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IDENTIFICATION AND VALIDATION OF NEW ANTHROPOMETRIC TECHNIQUES FOR QUANTIFYING BODY COMPOSITION

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This study validates estimates of body composition from bioelectrical impedance (RJL Model BIA-101) against corresponding estimates of body composition from densitometry in a sample of 177 young men and women, of whom 14% were black. Also, comparisons are made between measures of subcutaneous adipose tissue thickness using a portable ultrasound machine (EchoScan 1502) and Lange skinfold calipers in the same sample. In separate samples, measures of machine reliability were conducted between pairs of impedance machines and between pairs of ultrasound machines. In addition, tests were made of the possible effects of "physiological noise factors" on measures of impedance.

Bioelectric impedance is highly reliable as are measures of subcutaneous adipose tissue with Lange skinfold calipers. Ultrasonic measures of subcutaneous adipose tissue are not reliable and do not improve predictions of body composition over that of corresponding skinfold measurements.

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Bioelectric impedance is not affected by physiological factors such as diet, time of day, exercise or the menstrual cycle. However, in those women who do not participate in some form of regular exercise, predictions of body composition from Stature^2/Resistance plus anthropometry do differ significantly from those of women who do exercise regularly. The addition of bioelectric impedance does improve the predictions of body composition from anthropometry alone compared to corresponding estimates from densitometry.

The use of the RJL model BIA-101 biological impedance machine to measure body composition is recommended, with reservations, but the measurement of subcutaneous adipose tissue with the EchoScan 1502 portable ultrasound machine is not recommended.

SUMMARY

The purpose of this study was to validate estimates of body composition (percent body fat, total body fat, and fat-free mass) from measures of bioelectric impedance using new equipment (RJL Bioelectric Impedance Analyzer Model BIA-101) against corresponding estimates from measures of body density by underwater weighing in 177 young men and women. Measures of subcutaneous adipose tissue thickness by a portable ultrasound machine (EchoScan 1502) were compared to corresponding adipose tissue thicknesses measured with a Lange skinfold caliper in the same sample. The study sample matched the ages of the 1966 and 1977 U.S. Army studies of men and women who were between the 10th and 90th percentiles for age, and efforts were made to obtain a 14% representation of blacks. This level of black representation was achieved for men but not for women.

The Model BIA-101 impedance machine and the EchoScan 1502 ultrasound machine are relatively new scientific instruments. Therefore, instrument reliability was established as measurement repeatability between pairs of Model BIA-101 impedance machines and between a pair of EchoScan 1502 ultrasound machines. Measures of repeatability were determined within and between observers in a small sample of men and women (N about 20). In addition, influences of possible "physiological noise factors" on the resistance measures were determined. This part of the study consisted of hourly measures of resistance from 9 am to 5 pm in men and women (N=4) and daily measures of resistance for 35-day periods in 29 women, eleven of whom were taking oral contraceptives and eighteen of whom were not. Also, 24-hour recalls of diet, drugs, physical activity, smoking, and drinking and a menstrual history were collected from all participants as appropriate.

Findings from this study show that the Bioelectric Impedance Analyzer (BIA) is a very reliable instrument (99-100%) with little intra- or interobserver error (98-100% reliability). The Echoscan 1502 ultrasound instrument, however, is not very reliable (0-70%, depending on the site), even in the hands of trained and experienced technicians. Validation of bioelectric resistance against body density (BD) indicated that this approach has considerable potential. Root mean square errors (RMSE) of percent body fat (%BF) estimates based on stature^2/resistance plus simple anthropometry were 3.9% in women and 4.0% in men. This result is excellent because validation of any technique using BD involves a minimum of 2.5% error associated with estimates of %BF from BD.

Studies of physiological noise factors on estimates of %BF from bioelectric impedance indicated that the effects of time of day, time since last meal or drink, menstrual cycles of the women, and use of oral contraceptives were negligible. However, underestimates of %BF, relative to results from BD, did occur in those women who did not habitually engage in some form of physical exercise. Further research is suggested to determine the nature and extent of these exercise effects.

Contrasts of the data for black and white subjects indicated that separate regression equations need to be derived for these two groups. Further research efforts should include validation of equations for white men and women, derivation of equations for black men and women, and consideration of the need for individual equations for other racial/ethnic groups as well.

Validity tests of the Echoscan 1502 ultrasound machine indicated that the inclusion of ultrasonic measurements in predictive models did not significantly improve estimates of BD over those available from skinfolds and/or stature^2/resistance. Lack of significant improvement in estimates of BD, low machine reliability, and high observer error in the hands of experienced technicians all indicated that the Echoscan 1502 ultrasound machine not be recommended over the use of standard skinfold calipers. Instead, it is recommended that standard skinfold calipers be employed in all studies of regional body fatness, and that further research be undertaken to refine the use of bioelectric resistance in estimating total body fatness. Bioelectric resistance could then be used routinely in large scale anthropometric surveys and in screening individuals with regard to body composition variables.

PREFACE

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IDENTIFICATION AND VALIDATION OF NEW ANTHROPOMETRIC TECHNIQUES FOR QUANTIFYING BODY COMPOSITION

INTRODUCTION

RELEVANCE OF BODY COMPOSITION

The measurement of the composition of the human body in terms of amounts of bone, muscle, and adipose tissue by relatively simple and easy methods is of considerable interest to civilian health professionals. This interest is due largely to the fact that an excess of adipose tissue places a person at increased risk for hypertension, adult-onset diabetes mellitus (non-insulin dependent), hypercholesterolemia, hypertriglyceridemia, cardiovascular disease, gallstones, arthritis, gout, and some forms of cancer (1,2). Body composition is related also to physical performance whether performance is measured in relation to strength, endurance, or oxygen consumption (3,4). Body weight alone is not an adequate measure of obesity (5-7) because excess body weight may be due to an excess of fat-free mass (FFM) and not to an excess of total body fat (TBF) or an excess of the percentage of the weight of the body that is fat (percent body fat, %BF). Therefore, if risk of disease or the impairment of physical performance is to be evaluated in relation to obesity, it is necessary to fractionate the body into its gross components.

Body composition is of importance to the Army for many of the same health reasons it is of interest to civilians. Obese military personnel, like their civilian counterparts, are at increased risk for hypertension, diabetes, cardiovascular disease, etc., and they have decreased levels of physical performance. Many of these are middle-aged and older persons whose maturity, experience, and training are important to the U.S. Army. It is necessary to identify and reduce the prevalence of obesity in this group, but more important, to identify and treat younger groups at risk for obesity, thus improving their overall health, level of performance, and opportunity for continued service in the Army. In addition, the Army has another specific interest in the body composition of its personnel. The Army must provide a wide range of clothing and equipment essential to fulfilling its mission. There is a practical limit to the ranges of body size and shapes for which clothing can be made available or equipment designed for proper operation. Obese individuals may not be able to wear standard issued clothing or may have difficulty operating equipment. The ability to accurately and easily quantify the body composition of such obese persons would allow for correction (by weight loss or physical training) to be implemented at local command levels.

REVIEW OF STANDARD METHODS

Whole Body Measurements

Body composition can be estimated with reasonable accuracy by one of several "direct" methods such as densitometry, total body potassium, the measurement of total body water (TBW) or, more recently, by the measurement of total body electrical conductivity (8). Direct methods of estimating body composition quantify a single tissue or body component. This is usually TBF or FFM, either of which can be subtracted from body weight to yield the other. There are also numerous indirect methods of estimating %BF, TBF, and FFM from combinations of age and various body measurements in multiple regression equations (9-16). These methods require the measurement of multiple variables according to carefully standardized techniques.

Direct estimates of TBF and FFM are calculated most commonly from body density obtained from underwater weighing. This method is generally regarded as the standard against which the validity of other methods is judged (13). BD is calculated using data from standardized hydrostatic weighing under water. This method uses Archimedes' principle that a body submerged in water is acted on by a buoyancy force. This results in a loss of weight by the submerged body equal to the weight of the water displaced by the submerged body. Since the density of water is known, the volume of the body can be determined from the weight of the displaced fluid. For example, a materially homogenous object with a weight in air of 3.0 kg and a submerged weight in water of 1.0 kg has a weight loss of 2.0 kg. If the water is at a temperature of 35°C, then its density is 0.994 kg/L, and the volume of the water displaced is 2.0 kg/0.994 kg/L or 2.012 L. Thus, the density of the body is 3.0 kg/2.012 L or 1.491 kg/L.

The human body is composed of a mixture of components. If the densities of these components and the density of the whole body are known, the proportional masses of the components can be determined. However, in determining the density of the human body, a correction must be made for air trapped in the lungs while the person is submerged at maximum expiration. This is accomplished by measuring residual lung volume (RV) on land with the person in approximately the same body position as when submerged. Residual lung volume (RV) is measured rather than other lung volumes, e.g., total lung capacity, because RV is a more reproducible procedure (17) and is more similar to the volume of respiratory air present in the lungs when a person is being weighed underwater. It is not appropriate to use RV estimated from anthropometric data (18,19).

The equation for calculating body density is as follows:

$$BD = \frac{W_a}{\frac{W_a - W_w}{D_w} - RV}$$

where

BD = body density,

W_a = participant weight in air,

W_w = participant weight in water,

D_w = density of water at selected water temperature,

RV = residual lung volume.

The value of BD is converted to %BF using the formula of Siri (20): %BF = [(4.95/BD) - 4.50] x 100. The Siri equation yields results that are almost identical to those of the equation of Brozek (21), except at smaller values of BD where the Siri equation produces larger estimates of %BF (13). It is known that the Siri equation leads to systematic errors when applied to women and to blacks (13,22), but at present, there are no alternatives except an equation proposed recently for young women (%BF = (5.09/BD - 4.65) x 100) by Lohman (23).

The total error of measurement for a single estimate of BD from underwater weighing is composed of the errors involved in three separate measurements: body weight in air, body weight underwater, and residual lung volume. Analyses of the errors involved in determining BD using basically similar techniques give values ranging from 0.0004 (optimal) to 0.0043 density units (gm/cm^3). The smaller value is probably too low, and a more realistic value is an error of about 0.0023 density units in adults and children (24-26). Over the range of usual adult densities, the inherent percentage error in the underwater weighing technique is approximately 0.2 to 0.3 percent. Keys and Brozek (27) reported a coefficient of reliability (CR) of 95% for underwater weighings taken seven days apart. Similar findings have been reported by others (28,29). Mean inter-observer differences for underwater weights in The Fels Longitudinal Study conducted at the Division of Human Biology, Wright State University, School of Medicine, have ranged from 0.003 to 0.10 kg and have been 60 ml for residual lung volume (30,31). The CR for underwater weighing in the Fels data is 94.9% (31), and the observer differences for these measures have been near the middle of the range of values reported in the literature, although many of the Fels data are for children (16,32-36).

While errors in the determination of body density by underwater weighing are small, the accuracy of estimating %BF, TBF, or FFM by this method is unknown. Body density by underwater weighing assumes fixed densities for fat and FFM across age, sex, and ethnic groups, despite some evidence to the contrary (15,22, 35,37,38). If there were no error in measuring BD, the uncertainty in the estimates of %BF from BD would still be $\pm$ 2.5% (13).

Instead of estimating FFM from BD determined in underwater weighing, FFM can be estimated using ^{40}K (39-41). Approximately 98% of the potassium (K) in the body is intra-cellular, and radioactive ^{40}K comprises 0.0118% of the total potassium in the body (42). FFM is calculated on the assumed basis that the K content of FFM is 68.1 meq/gm for men and 65.2 meq/gm for women (43). Although the ^{40}K method of calculating FFM is highly reliable in adults (28,44), it does not take into account the differences in the K content of FFM between those who perform much physical activity and those who do not, so it may underestimate FFM in the obese (45-47). Also, the K content varies among muscles and organs of the body (48), and the proportions of FFM that are muscle, skin, bone, etc., vary between and within sex-, ethnic-, and age-specific groups (49-52).

Another method of estimating body composition is to measure total body water (TBW). This method assumes that FFM has a constant water content and that body fat is anhydrous (53-55). The FFM of young adults is considered to be about 72% water, but the water content of adipose tissue, as opposed to body fat, is 10% to 30% in lean individuals and as low as 5% in the obese (42,56). Methods of measuring TBW are based on the dilution of deuterium, tritium, urea, antipyrine, ^{18}O, thiocyanate, or alcohol (39,53,57-60). All these methods require time for equilibration within the subject, or dubious extrapolation, and careful supervision that fluids are not taken and all urine is collected. Such procedures are difficult for both the subject and the investigator, and the data require adjustments for water gain or insensible water loss. Finally, the space measured may not correspond to the "water compartment" because of exchange with atoms in molecules other than water, particularly protein (61).

Another method of determining body composition is to measure body volume. If the volume and weight of the body are known, its density can be calculated. Air displacement can be used instead of underwater weighing to measure body volume (62,63). The theoretical basis is the Ideal Gas Law which should apply to the behavior of air at ordinary room temperatures and pressures. The method is difficult to apply because of the water vapor in expired air and the occurrence of temperature changes. Body volume can also be measured in air using the dilution of inert gases such as helium or krypton (58,64). The participant enters one chamber and a known volume of inert gas in a second chamber is mixed with the air in the first chamber. After equilibrium is reached, the concentration of the gas is measured and body volume calculated. Calibration is difficult, as is measurement of the concentration of the gas. Also, equilibration takes a long time which places a burden on both the participant and the investigator. The basic principle is sound, but problems must be addressed in order to arrive at accurate, cost-effective results.

Total body electrical conductivity (TOBEC) is a newer method to estimate TBF, and some encouraging validation data have been reported (8, 65-68). The person is placed within a large solenoid coil with a 5-mHz oscillating radio frequency current. The oscillating field of the coil induces a current in the person thereby changing the coil impedance which can be measured very accurately.

Estimates of FFM and TBF by ^{40}K generally compare well with corresponding estimates from other direct methods. Correlation coefficients among estimates of FFM in adults by ^{40}K, BD, and TBW range from +0.65 to +0.94 (45,49,50). Despite these rather high correlations, some large differences occur between the estimates from ^{40}K and BD for individuals (45,51,52). However, density and hydrometry usually yield similar results when applied to individuals (69-71). The TOBEC method has not been fully validated.

There are important logistical limitations with each of the direct methods of estimating body composition. Densitometry requires a large tank of water and specialized equipment for recording underwater weight and measuring RV. The subject must change into a swim suit and submerge at complete exhalation. The measurement of ^{40}K is time-consuming and requires the subject to be isolated in an enclosed cylinder or booth. In addition, sensitive detection equipment and pre-World War II steel must be used in the construction. Pre-World War II steel was forged before atmospheric nuclear testing and does not contain additional gamma radiation. Measures of TBW require the precise administration of chemicals or radioactive isotopes followed by a period of 4 to 12 hours of supervised complete fasting before the collection and analysis of blood, urine, or saliva specimens. The TOBEC method is rapid, but it is incompletely tested and requires specialized expensive equipment. Each of these methods require large, expensive, specialized laboratories and several highly trained personnel.

Regional Body Measurements

The body composition techniques discussed in the preceding paragraphs concern the whole body. However, regional measures of adipose tissue, muscle, and bone can provide important information relating to risk of disease, affect body size and shape and may be used to estimate total body composition (2,72,73). Skinfold thicknesses are one type of regional measurement. Skinfold thicknesses, together with circumferences at the same levels as the skinfolds, can be used to estimate cross-sectional adipose tissue and muscle areas of the upper arm or calf. Each of these tissue areas are significantly correlated with TBF or FFM (74). These estimates of adipose tissue and muscle tissue areas are based upon the assumption that cross-sections of the upper arm and calf consist of concentric rings of adipose tissue, muscle, and bone. These estimates can also be based upon a formula that provides estimates more nearly matching the actual distributions of these tissues (75).

The large variations in correlation coefficients among skinfold thickness at different sites and with TBF in adults emphasize the importance of appropriate site selection (10,35,76-80). Selection of a site for skinfold measurement is limited by the need to "pick-up" a skinfold. This excludes measures of skinfolds at sites such as the breasts, which are estimated to contain 3.5% of the body fat of women (81). Also, skinfold calipers cannot be used in the obese (82). In addition, skinfold sites should be located with reference to bony landmarks. This is impossible over the buttocks, where a skinfold can be picked up, with its long axis horizontal, in the posterior midline of the thigh just proximal to the gluteal fold (83), but site location relative to skeletal landmarks is uncertain. This topic has been reviewed recently (2,73). There are other disadvantages to the use of skinfold calipers. They compress subcutaneous adipose tissue to an extent that varies from one individual to another (84). Consequently, useful adjustments for compression cannot be made for individuals unless uncompressed thicknesses are available. Valid, uncompressed data can be obtained from radiographs by measuring the thickness of a subcutaneous adipose tissue shadow on a radiograph (85). However, positioning the body for radiography is difficult, and more importantly, this method involves radiation.

Skinfold measurements have been validated by comparison with data from direct postmortem measurements (78,86-89). Correlations between values from skinfolds and corresponding radiographic measurements are about + 0.8 in adults (78,90-95). There are few logistic problems in using skinfold calipers to measure subcutaneous adipose tissue thickness. Skinfold calipers are relatively inexpensive, easily portable, and simple to use. They do not require extensive training of personnel for accurate use, they do not cause pain, and the procedure is non-invasive. As a result, skinfold calipers are widely used in screening programs and in large anthropometric and nutritional surveys from which there is an extensive body of data (96-98).

REVIEW OF NEW METHODS

Whole Body Measurements

The newest method of measuring total body composition is bioelectric impedance. Electrical impedance is the opposition of a material to the flow of an alternating electrical current that is frequency dependent (99). Impedance is analogous to the resistance of a conductor to a direct current. The use of bioelectric impedance to measure body composition is based upon the difference between FFM and TBF in their abilities to conduct an alternating electric current at low frequencies (100). The difference in the conductivity of these body constituents is a reflection of differences in their water and electrolyte concentrations (100,101).

From Ohm's Law, electrical impedance is directly proportional to the length of the conductor and inversely proportional to its cross-sectional area, assuming that the current is directly proportional to the potential difference between the ends of the conductor. If impedance (Z) is proportional to the length of the conductor and to its volume resistivity in ohms-cm (p), and inversely proportional to its cross-sectional area (A), Z is proportional to pLength/A. If volume (V) is the product of length and cross-sectional area, V = Length x A, then A = V/Length, and by substitution, Z = pLength x Length/V, and V = $pLength^2/Z$. Thus, based on the assumption that stature (S) represents the length of the conductor, and that bioelectric impedance is an index of FFM, the volume of FFM in the body is proportional to $stature^2$ divided by impedance.

Electrical impedance is also equal to the square root of the sum of the square of the resistance and the square of the reactance. Reactance is produced in the human body by the capacitant effects of tissue interfaces and cell membranes. However, if the value of reactance is small compared to the value of resistance, then the latter can be used as a measure of impedance (102). Recently, Lukaski and coworkers (99) reported an extremely high correlation coefficient (+0.99) between values of impedance and resistance. Also, they reported that correlations of either impedance or resistance alone with measures of body composition were almost identical (99). In practice, bioelectric resistance is measured rather than bioelectric impedance, and the ratio $stature^2$/resistance is used as an index of FFM. In small samples, $stature^2$/resistance is closely associated with measures of TBW and FFM from densitometry or ^{40}K (99,101, 103-108). Failure to appreciate the basic importance of $stature^2$/resistance in this context can result in misleading findings (109).

The reliability of bioelectric impedance and resistance measurements appears to be excellent (99,110-112). The standard errors of the estimates (SEE) of FFM are reported to be smaller with the Bioelectrical Impedance Analyzer (BIA) (2.1 to 3.6 kg) than with the TOBEC instrument (3.8 to 11.2 kg), but these conclusions are based on small samples among which there are differences in the "direct" methods that were applied (8,66,68,99,106,113,114). Errors of the estimates are due, in part, to biological variations in FFM between individuals that lead to errors in measurements of TBW or BD (56,115). There is little doubt that improvements are needed in the estimation equations supplied by the manufacturer of the BIA instrument (107,110,111). It has been claimed that %BF can be estimated better by a series of circumferences than by impedance (110), but supporting data have not been reported.

Regional Body Measurements

Ultrasonic measurements of subcutaneous adipose tissue thickness have several advantages over the use of skinfold calipers. Ultrasonic measurements are not affected by inter-individual differences in tissue compressibility (84). In addition, ultrasound has the potential advantage that it could be used at body locations where skinfolds cannot be measured effectively, such as breast and buttocks, and where the skinfold is too large or cannot be separated from underlying tissue as is common over the abdomen in the obese. Despite these apparent advantages, ultrasound has not been used commonly to measure subcutaneous adipose tissue thickness. This is because early instruments were nonportable or two technicians were required (95), and the estimation of adipose tissue thickness was made from the horizontal axis of an oscilloscope (116). Measurement errors for these instruments were considerably larger than those for skinfold calipers (82). One recently developed portable instrument (ITHACO) uses light emitting diodes with an accuracy of 2.0 mm, but measurement errors with this instrument are considerably larger than those with skinfold calipers (82,117,118).

Ultrasonic measurements must be made at places where there is a greater thickness of subcutaneous adipose tissue than the minimum reading of the instrument and where there is a relatively flat muscle - adipose tissue interface. Ultrasonic measurements of subcutaneous adipose tissue thickness are positively correlated with corresponding caliper and radiographic measurements in adults, except at sites where bone is near the surface or numerous muscle interfaces are present (82,95,116,119-121). The presence of interfaces is an individual characteristic that can be determined only by ultrasound in the living. Ultrasonic measurements of subcutaneous adipose tissue are significantly correlated with BD or TBF in small samples, but these correlations are generally lower than those for skinfold thicknesses (83,120-123).

There appear to be few logistic problems with the taking of bioelectric impedance and ultrasonic measurements. Both pieces of equipment are light, can run on batteries, and do not require extensive personnel time or training. However, errors associated with the equipment, the technicians, and methodology are unknown. The current research investigates these phenomena in two new systems: the Bioelectric Impedance Analyzer, BIA-101, and the Echoscan 1502 ultrasound machine.

DESCRIPTION OF EQUIPMENT TO BE TESTED

Bioelectric Impedance Analyzer

The Bioelectric Impedance Analyzer, Model BIA-101, is manufactured by RJL Systems, Inc., 9930 Whittier, Detroit, Michigan 48224. The analyzer weighs 1.06 kg and uses a 4-electrode system. The two source electrodes introduce a painless, harmless alternating current of 800 microamps at 50 kHz $\pm$ 2%. Two measuring electrodes are placed between the source electrodes to measure the electric impedance of the conductor. Placement of the electrodes is shown in Figure 1. The participant does not have to undress or be electrically grounded, and there is no possibility of electric shock. The apparatus should be calibrated twice daily with a test object.

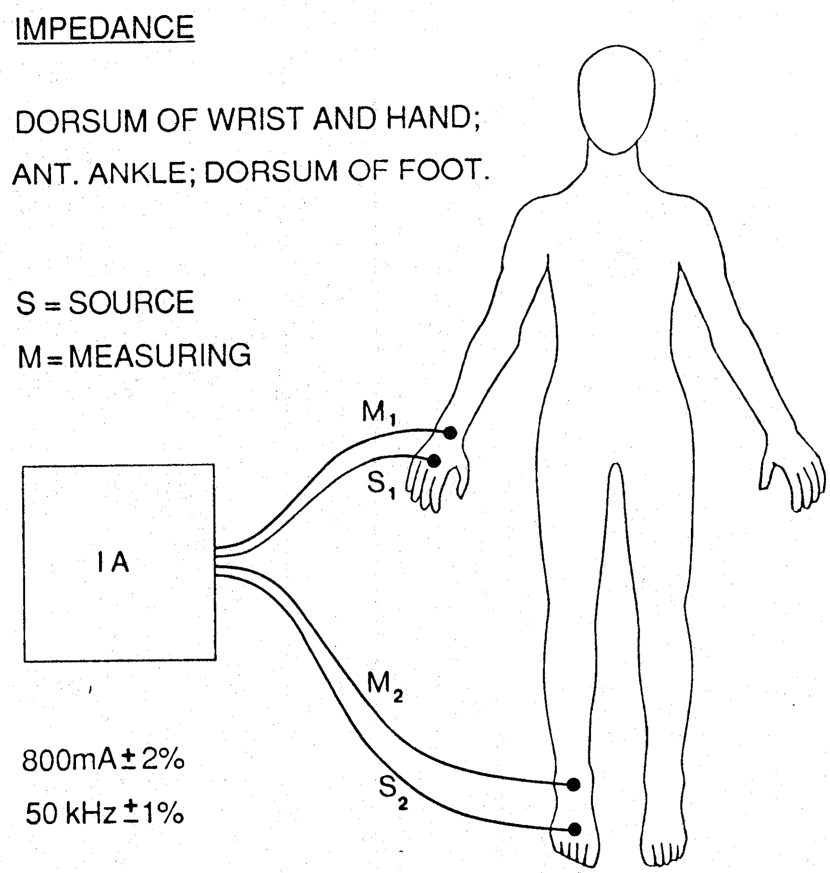

Figure 1. Placement of electrodes for the Bioelectric Impedance Analyzer

EchoScan 1502

The EchoScan 1502 is an ultrasound machine that uses a single crystal, 5 mHz transducer, 0.8 cm in diameter. This machine has a digital display accurate to 0.01 cm based upon a rate of transmission of sound through adipose tissue of 1450 m/sec. The EchoScan 1502 is manufactured by Par Scientific Instruments Aps, Orstedsgade 16, DK-5900 Rudkobing, Denmark. With this equipment, an operator can select different sound velocities and measurement depths. The EchoScan is calibrated internally to the manufacturer's transducer, but it can be calibrated to use other transducers with different time delays.

OVERVIEW OF EXPERIMENTS CONDUCTED

Replicability

The Bioelectric Impedance Analyzer and the EchoScan 1502 are new equipment for which observer and machine errors have not been reported. Each of these machines was tested to determine intra- and inter-machine differences by the same and different observers. These tests helped to determine the amount of error in each reading that is due to the person taking the measurement, the person being measured, and the machines. If the equipment were accurate and the observers careful, these components of error should not be significant. The tests were designed to determine the amount of error expected to occur in a field setting with different machines and with different observers.

Questionnaire data were also obtained about handedness, particularly for gross motor tasks, and about the extent to which one side of the body was used differentially in physical work. These data were obtained from each subject and were used with resistance data in analyses to determine whether there was a significant effect of handedness.

Validity

After it was determined that the new equipment was accurate, measurement validity was tested. Bioelectric impedance is supposed to provide a measure of FFM that can be used alone or in combination with other body measurements to estimate body composition. The validity of bioelectric impedance was assessed by the improvement in the R^2 and SE when BD from underwater weighing was predicted from impedance combined with anthropometric data compared with predictions from anthropometric data alone.

The EchoScan 1502 should provide measures of subcutaneous adipose tissue thickness at specific body sites, free of the effects of compression produced by skinfold calipers. In addition, ultrasonic measures of subcutaneous adipose tissue should be of equal, if not greater value, than skinfold measurements in predicting body composition. Validity of ultrasonic measurements was tested by taking corresponding ultrasonic and skinfold measurements from the same group of men and women, plus some ultrasonic measurements from body sites where skinfolds were not possible. True tests of the validity of the ultrasonic measurements would be possible only by comparison to corresponding measurements taken from radiographs. Since this was impossible, the validity of the ultrasonic measurements was investigated by determining if their values improved the estimation of body composition over that of corresponding skinfold thicknesses.

Physiological Factors

The influence of diurnal variation and of menstruation on the conductivity of the body was studied using serial data from small samples. This part of the study provided important evidence consistent with findings from the larger cross-sectional sample.

The effects of diurnal variation on bioelectric impedance were examined in the cross-sectional study. All subjects were questioned regarding interval from last meal/drink and the nature and amount of the last meal/drink, elimination (urine, feces) and their recent involvement in exercise. In addition, a few subjects were measured with the BIA instrument on the hour between 0900 and 1700 hours. Night-time values were not obtained because they would have little practical interest. The subjects' activities were not controlled, but each kept a diary regarding activities (consumption of food and drink, urination, exercise, etc.) during the day.

Thirty-five women over 18.5 years of age were selected without reference to the nature of their menstrual cycles (duration, amount, regularity). For 35 consecutive days, each woman had a measure of bioelectric impedance and each was questioned about health activities during the previous day, about menstrual characteristics (when appropriate) and about details of current oral contraceptive use. This part of the study was included so that within-subject changes in bioelectric resistance, perhaps associated with premenstrual water retention, could be related to timing within the menstrual cycle.

Short-term dietary differences could influence bioelectric impedance by altering the body content of water and electrolytes. Dietary differences could also alter skinfold measurements because of changes in compressibility, but there is no basis for expecting they would affect the ultrasonic measurements of subcutaneous adipose tissue thicknesses. Therefore, 24-hour dietary records were obtained and the timing of intakes of food and drink were used as co-variates in analyses of the differences between measured and predicted body composition values.

Questionnaire data relating to exercise during the week and 24 hours prior to testing were also obtained. Exercise could have an influence on bioelectric impedance, particularly if fluids lost have not been replaced.

There is no logical reason to expect real racial differences in regard to any aspect of the study other than accuracy. Consequently, analyses relating to racial factors were restricted to accuracy and, for logistic reasons, the comparisons were restricted to black versus white differences. Racial group membership was obtained by self-report.

REPLICABILITY

RATIONALE

Replicability is important because of the differences that can occur in the values of repeated body measures made by the same or different measurers using one or more pieces of the same measuring equipment. If these differences are large, they will obscure estimates of the true values for measures of body size, shape, composition and function. If equipment is manufactured properly, is well maintained and kept calibrated, any error of measurement by the same or by two separate pieces of the same type of equipment should be very small, and the largest source of error will be due to the person or persons taking the body measurements. For equipment that has become common in its usage, intra- and inter-machine and intra- and inter-observer errors generally have been reported. For newly marketed equipment, however, there is frequently only limited information provided by the manufacturer and field tests are lacking. Because this contract tested two new types of equipment, it was important to determine the reliability of the equipment and the level of observer errors to be expected with the equipment, and how these errors compare to those of equipment presently used in surveys. If the equipment is not reliable or the observer errors cannot be kept within acceptable limits, then the equipment cannot be recommended.

MACHINE REPLICABILITY

Hypotheses

To determine the amounts of machine error, the following hypotheses were tested:

1. There are no differences in repeated measures of bioelectric resistance using one or two BIA-101 Bioelectric Impedance Analyzers.

2. There are no differences in repeated ultrasonic measures of subcutaneous adipose tissue thickness at a site using one or two EchoScan 1502 ultrasound machines.

Sample and Methods

Sample

Machine replicability was tested using a sample of 24 healthy young adults who were each measured twice with two Model BIA-101 bioelectric impedance analyzers and two EchoScan 1502 ultrasound machines. All measurements were collected from each participant in this sample on the same day. Within this sample, there were 12 white men, 18.0 to 34.2 years of age and 12 white women, 18.2 to 29.9 years of age. The distributions for age, stature, and weight of these participants are presented in Table 1. All measures of participants in the machine replicability study were collected using facilities at the Department of Physical Education, Cedarville College, Cedarville, Ohio. The forms for informed consent and data collection are in Appendix A.

TABLE 1. Distributions for Age, Stature and Weight in the Machine Replicability Sample.

	N	Age Mean (Years)	Age SD	Stature Mean (cm)	Stature SD	Weight Mean (kg)	Weight SD
Men	12	21.9	4.2	179.5	6.7	79.6	9.0
Women	12	21.6	3.2	165.4	4.1	61.9	5.1

Methods

Bioelectric Impedance. Bioelectric impedance was measured as bioelectric resistance with two RJL Systems Model BIA-101 analyzers. Bioelectric resistance was measured twice on the right side of each participant by each of two observers working independently with two separate machines. The participant was supine with the arms resting alongside but not touching the body, and the legs separated (25 cm between medial malleoli) so that there was no contact between the legs. Each participant was dressed in a swimsuit or shorts and a T-shirt. The electrodes were attached to the body using 4 cm of electrode tape and a small amount of electrode cream at each site. The placement of the electrodes is described in Appendix B.

After attaching electrodes to the participant, the red and black cables were connected to the first BIA analyzer, and two measures of bioelectric resistance were recorded separately by each observer. After these resistance measures had been taken and without removing the electrodes from the participant's body, the red and black cables were connected to the second BIA analyzer. Using the second analyzer, each observer again separately recorded two measures of bioelectric resistance.

Ultrasound. Ultrasonic measures of subcutaneous adipose tissue thickness were taken at the same body locations with two EchoScan 1502 portable ultrasound machines. The body sites were on the buttocks and the superior breast plus the same sites used for measures of skinfold thicknesses at the triceps, biceps, subscapular, mid-axillary, paraumbilical, anterior thigh, and lateral calf sites. The measurement location of each body site was marked on each participant. Using the first ultrasound machine, measurements were recorded twice by each of two observers working independently. The same procedure was then repeated using the second ultrasound machine. The anatomical location of each ultrasonic measurement is given in Appendix B.

For each ultrasonic measurement, one observer held the transducer lightly against the skin of the participant at the marked location avoiding tissue compression. The transducer was held perpendicular to the surface of the skin with an interface of ultrasound transmission gel. The second observer monitored the readout part of the EchoScan instrument and made adjustments to the gain to determine the thickness of the subcutaneous adipose tissue at that location. The value recorded for a measurement was assigned to the observer who monitored and adjusted the EchoScan machine.

Results and Discussion

Results

Hypothesis 1

Intra-Machine Differences for Model BIA-101 Impedance Analyzer. Bioelectric resistance measures were taken by two observers each of whom recorded a pair of

TABLE 2. Distribution Statistics and Reliability for Intra- and Inter-Machine Differences for the Bioelectric Impedance Analyzers by Observer.

	N (pairs)	Mean[a] (ohm)	SD (ohm)	TE[b]	CV (%)	CR[c] (%)
Intra-Machine						
Analyzer 1						
Observer A	24	0.3	0.5	0.4	0.0	100.0
Observer B	24	0.3	0.5	0.4	0.1	100.0
Analyzer 2						
Observer A	24	0.9	1.8	1.4	0.3	100.0
Observer B	24	0.5	1.1	0.8	0.2	100.0
Inter-Machine						
Observer A	24	2.4	5.2	4.0	0.8	99.5
Observer B	24	2.4	4.4	3.5	0.7	99.7

a. Mean absolute differences
b. Technical error of measurement
c. Coefficient of reliability

measurements with two separate bioelectric impedance analyzers. The mean absolute difference for repeated bioelectric resistance measures was 0.3 ohm for both observers for analyzer 1 and 0.5 and 0.9 ohm for observers A and B, respectively, with analyzer 2 (Table 2). The largest intra-machine difference was 7.0 ohm. The technical errors of measurement (defined in Appendix F) were 0.4 ohm for both observers for analyzer 1 and 0.8 and 1.4 ohm for the two observers for analyzer 2. For both machines, regardless of observers, the coefficient of reliability (defined in Appendix F) was 100%.

<u>Inter-Machine Differences for Model BIA-101 Impedance Analyzers</u>. Mean absolute differences for repeated measures of resistance on the same participant using two analyzers were 2.4 ohm for both observers (Table 2). The technical errors of measurement (TE) between machines were less than 5.0 ohm for each observer. The largest inter-machine difference was 26.0 ohm, but the coefficient of reliability (CR) for both machines was 99.5% or greater.

Hypothesis 2

Intra-Machine Differences for the EchoScan 1502. The intra-machine mean absolute differences and estimates of reliability are presented in Tables 3 and 4. Because of missing data for some measurements, the data presented are for groups that vary in size from 17 to 24. The absolute differences were small with means of about 1.0 mm and SD values of 0.7 to 1.5 mm for the ultrasonic measurements by observer A using machine 1. Corresponding differences were slightly larger for observer A using machine 2 and slightly smaller for observer B when using either machine 1 or machine 2. The maximum differences for the ultrasonic measurements were as large as 7.2 mm. Most of the TE of the ultrasonic measurements were less than 1.0 mm with a range from 0.4 to 1.8 mm. The coefficient of variation (CV) values for the ultrasonic measurements ranged from 11.6% to 38.4%, and the

TABLE 3. Distribution Statistics and Reliability for Intra-Machine Differences for the EchoScan 1502 Ultrasound Machine 1 by Observers.

Ultrasound Site	N (pairs)	Mean[a] (mm)	SD (mm)	TE[b]	CV (%)	CR[c] (%)
Observer A						
Triceps	24	1.1	1.1	1.1	25.9	40.6
Subscapular	17	1.1	0.8	1.0	21.9	64.7
Biceps	24	1.0	0.7	0.9	24.0	58.3
Midaxillary	20	1.3	1.0	1.1	27.7	42.4
Breast	22	1.2	1.1	1.2	21.5	58.9
Paraumbilical	19	1.5	1.5	1.5	30.6	29.4
Anterior Thigh	24	1.2	1.4	1.3	20.8	56.6
Lateral Calf	24	0.9	1.0	1.0	24.2	67.1
Buttocks	20	0.9	0.8	0.9	15.7	46.2
Observer B						
Triceps	24	1.0	0.9	1.0	20.2	54.0
Subscapular	17	1.1	1.2	1.1	22.6	63.1
Biceps	24	0.5	0.4	0.4	13.0	74.9
Midaxillary	20	0.6	0.7	0.6	13.6	76.5
Breast	20	1.0	0.7	0.8	18.3	70.3
Paraumbilical	19	1.3	1.4	1.4	29.3	22.4
Anterior Thigh	24	0.7	0.8	0.7	11.6	75.5
Lateral Calf	24	0.7	0.7	0.7	16.5	74.8
Buttocks	17	0.8	0.7	0.7	12.9	74.1

a. Mean absolute differences
b. Technical error of measurement
c. Coefficient of reliability

reliability estimates varied from zero to 76.5%. Reliability tended to be high for the ultrasonic measurements at the lateral calf site and low for measurements at the biceps site, but there was marked variability in relative reliability among sites within observers and machines.

TABLE 4. Distribution Statistics and Reliability for Intra-Machine Differences for the EchoScan 1502 Ultrasound Machine 2 by Observers.

Ultrasound Site	N (pairs)	Mean[a] (mm)	SD (mm)	TE[b]	CV (%)	CR[c] (%)
Observer A						
Triceps	23	2.0	1.6	1.8	38.4	0.0
Subscapular	17	1.4	1.0	1.2	24.5	33.5
Biceps	23	1.0	0.6	0.8	23.5	58.2
Midaxillary	19	0.7	1.0	0.9	19.1	47.6
Breast	22	1.6	1.5	1.5	26.5	17.1
Paraumbilical	19	1.9	1.1	1.5	27.8	50.3
Anterior Thigh	23	1.5	1.1	1.3	21.5	30.1
Lateral Calf	23	1.0	0.8	0.9	21.4	74.3
Buttocks	20	0.9	1.1	1.0	16.3	55.5
Observer B						
Triceps	23	0.7	0.7	0.7	13.9	66.9
Subscapular	17	0.9	0.6	0.7	15.8	56.5
Biceps	23	0.5	0.6	0.6	18.2	56.2
Midaxillary	19	0.8	0.7	0.7	16.0	60.9
Breast	20	0.7	0.6	0.6	14.3	64.8
Paraumbilical	18	0.7	0.8	0.7	16.4	76.0
Anterior Thigh	23	0.8	0.8	0.8	14.8	56.5
Lateral Calf	23	0.6	0.7	0.7	19.4	52.6
Buttocks	17	0.7	0.7	0.7	12.9	69.5

a. Mean absolute differences
b. Technical error of measurement
c. Coefficient of reliability

Inter-Machine Differences for the EchoScan 1502. Distribution statistics, TE, CV, and CR for observer A and observer B are given in Table 5. These differences are likely to reflect variations in transducer placement more than they reflect true "machine" differences. The mean differences and the SD for ultrasonic measurements of adipose tissue thickness differed considerably among sites and between observers, but in general, both the means and SD values were close to 1.0 mm for observer A and slightly less for observer B. The differences tended to be large for the anterior thigh site and small for the biceps site with each observer. Also, the maximum inter-machine differences tended to be large for the lateral calf site and small for the biceps and buttocks sites with each observer.

TABLE 5. Distribution Statistics and Reliability for Inter-Machine Differences for the EchoScan 1502 Ultrasound Machine by Observers.

Ultrasound Site	N (pairs)	Mean[a] (mm)	SD (mm)	TE[b]	CV (%)	CR[c] (%)
Observer A						
Triceps	23	1.3	0.9	1.1	24.1	19.8
Subscapular	17	1.1	1.0	1.0	22.1	48.3
Biceps	23	0.8	0.6	0.7	19.0	66.8
Midaxillary	19	1.4	0.9	1.2	26.8	0.0
Breast	22	1.0	1.0	1.0	17.7	54.5
Paraumbilical	18	1.6	1.5	1.5	29.3	20.4
Anterior Thigh	23	1.4	1.2	1.3	21.1	27.5
Lateral Calf	23	1.0	1.2	1.1	26.8	39.0
Buttocks	20	1.1	0.7	0.9	15.5	43.5
Observer B						
Triceps	23	1.1	0.9	1.0	20.1	15.8
Subscapular	17	0.9	0.7	0.8	16.9	65.2
Biceps	23	0.4	0.3	0.4	12.0	75.6
Midaxillary	19	0.7	0.8	0.7	16.1	54.3
Breast	22	1.0	0.8	0.9	20.5	39.0
Paraumbilical	18	0.8	0.7	0.8	16.7	66.4
Anterior Thigh	23	1.2	0.9	1.0	17.9	36.5
Lateral Calf	23	1.0	1.0	1.0	26.0	3.0
Buttocks	20	0.9	0.8	0.8	14.7	57.8

a. Mean of absolute differences
b. Technical error of measurement
c. Coefficient of reliability

The TE tended to be large for the lateral calf site and small for the biceps and buttocks sites when data for the two observers were considered. When the mean values were taken into account by calculation of the CV, there were relatively low values for the buttocks site and high values for the lateral calf and paraumbilical sites. The CR differed markedly from site to site, being high for the biceps, breast, and subscapular sites and low for the triceps, midaxillary, and lateral calf sites.

Discussion

Machine errors for the Bioelectric Impedance Analyzers are very small, and the reliability within and between machines was excellent. The machine errors for the EchoScan 1502 were small for both machines regardless of observers, but the reliability within and between machines was fair (50-70%) to poor (< 50%).

OBSERVER REPLICABILITY

Hypotheses

To determine the amount of observer error, the following hypotheses were tested:

1. There are no differences between repeated measures of bioelectric resistance by the same or different observers.

2. There are no differences between repeated ultrasonic measures of subcutaneous adipose tissue thickness at a site by the same or different observers.

3. There are no differences between repeated measures of stature, weight, arm, and calf circumference, skinfold thickness, underwater weights, or residual lung volumes by the same or different observers.

4. There are no interaction effects within or between observers and machines for measures of bioelectric resistance and ultrasonic measures of subcutaneous adipose tissue thickness.

Sample and Methods

Sample

These hypotheses were tested using data from a cross-sectional sample of 177 healthy young adults who each participated in measures of underwater weighing, anthropometry, residual volume, bioelectric resistance, and ultrasonic measures of subcutaneous adipose tissue thicknesses. Within this sample, there were 78 white men (19.0 to 27.3 years of age), 15 black men (18.8 to 27.8 years of age), 75 white women (18.3 to 29.8 years of age), and 9 black women (19.0 to 29.4 years of age). Blacks comprised 14.3% of the total sample. These participants were selected so that their chronological ages at the times of examinations were within the 10th and 90th percentiles of age for U.S. Army men and women at the time of the 1966 and 1977 studies of U.S. army personnel (Table 6). There was slight oversampling of the third quartile and slight undersampling of the first and fourth quartile for age within each sex. Sex, age, and race were the only criteria for selecting participants. The forms for informed consent and data recording are in Appendix A.

TABLE 6. Percentile Distributions of Age by Sex and Racial Groups Within U.S. Army Surveys and the Present Sample.

	Percentile Groupings			
	10.0–24.99%	25.0–49.99%	50.0–74.99%	75.0–90.0%
MEN				
1966 Army Survey				
Ages (years)	19.1–19.6	19.7–20.6	20.7–23.0	23.1–27.4
Present Study				
Whites				
Ages (years)	18.9–19.6	19.8–20.6	20.7–22.9	23.1–27.3
N	15	19	29	15
Blacks				
Ages (years)	18.8–18.9	19.9–20.3	20.7–22.9	24.5–27.8
N	2	4	7	2
Total N	16	23	36	18
WOMEN				
1977 Army Survey				
Ages (years)	18.5–19.5	19.6–22.5	22.6–25.6	25.7–29.9
Present Study				
Whites				
Ages (years)	18.3–19.5	19.6–22.4	23.0–25.6	25.8–29.8
N	14	22	24	15
Blacks				
Ages (years)	19.0–19.2	20.3–20.9	22.9–25.5	29.4
N	2	2	4	1
Total N	16	24	28	16

Methods

Bioelectric Impedance. Bioelectric resistance was measured with an RJL Systems Model BIA-101 Analyzer as described on page 16 and in Appendix B. Resistance was measured twice on the right side of each participant by each of two observers working independently.

Ultrasound. Ultrasonic measures of subcutaneous adipose tissue thickness were made with an EchoScan 1502 portable machine as described on page 17, at the same body locations as the skinfold measurements, plus measures from the buttocks and from the breast. All ultrasonic measurements were recorded twice by each of two observers as described in Appendix B.

Underwater Weighing. Underwater weights were collected from each participant in this sample. This procedure was conducted using the facilities of the Human Performance Laboratory, Department of Physical Education, Wright State University. The water tank consisted of a heavy plastic cylinder, 1.5 m in diameter and 1.8 m high. The water in the tank was maintained with a depth of approximately 1.0 m at a temperature that ranged between 30° and $39^{\circ}C$ from day to day. The weighing apparatus consisted of a tubular plastic frame chair attached by plastic ropes to a Chatillon scale that had a maximum of 9.0 kg and measured to the nearest 10 g.

After each participant entered the tank, a tare weight was recorded for the chair before the participant sat down, and the water temperature was recorded. The participant then sat in the chair and submerged himself/herself by bending forward. This initial submersion was necessary to remove trapped air from the swimsuit and from the hair. The participant then sat up in the chair while instructions for the weighing procedure were explained. The participant was asked to bend at the waist until his/her body was completely submerged and simultaneously exhale to maximum expiration. The underwater weight was recorded after air bubbles stopped coming from the participant and all oscillations of the scale due to waves had subsided.

After listening to the description of the procedures and receiving answers to questions, each participant made a minimum of five unrecorded test weighings.

Many of the participants were familiar with underwater weighing, and five pretest weighings were sufficient to ensure that the participant understood the underwater weighing procedures. More than five pretest weighings were needed for a few participants who were afraid of water or apprehensive of the procedure. These extra weighings were to ensure that the participants were fully familiar with the procedures. The number of pretest weighings did not exceed ten for any participant.

Following the pretest weighings, ten underwater weights were recorded for each participant by each of two observers working independently. After the first ten underwater weights were recorded by the first observer, the tare weight of the chair and water temperature were recorded again. Then a second group of ten underwater weights were recorded by the second observer. The order of observers was random.

Residual Lung Volume. Residual lung volume (RV) was measured on land to the nearest 0.1 L by a nitrogen washout method (18). This procedure was conducted in the Department of Physiology, Wright State University using a Gould M100B Pulmonary Function Analyser. For this procedure, the participant sat in a chair alongside the Gould machine in a position similar to that assumed while submerged for underwater weighing. After breathing room air, the participant exhaled to maximum expiration and was immediately switched to breathing pure oxygen. The participant continued to breath pure oxygen until the nitrogen concentration in the expired air was less than 0.2%. Two measures of RV were recorded for each participant.

Anthropometry. The following anthropometric variables were recorded once by each of two observers independently: stature, weight, arm, and calf circumferences. The following skinfolds were recorded twice by each of two observers independently: triceps, biceps, subscapular, midaxillary, paraumbilical, anterior thigh, and lateral calf. Stature, weight, arm, and calf circumference and triceps, biceps, subscapular, and midaxillary skinfolds were recorded with the participant standing. Paraumbilical, anterior thigh, and lateral calf skinfolds were recorded with the participant supine. Skinfolds and circumferences were recorded from the right side of the body of each participant. Complete descriptions of each anthropometric technique are found in Appendix B.

Results and Discussion

Results

Hypothesis 1

Bioelectric Impedance Analyzer Model BIA 101. Intra- and inter-observer differences for men and women are presented in Table 7. In each sex, intra-observer differences for measures of resistance were small with values for the mean absolute differences, SD, and TE at about 6.0 ohm. The largest inter-observer difference was 27.0 ohm, but the CR was 98% or greater for each observer. Inter-observer differences were very small for both men and women. The largest inter-observer difference was 17.0 ohm, but the CR was extremely high.

Hypothesis 2

EchoScan 1502 Ultrasound Machine. Mean absolute intra-observer differences for measurements of subcutaneous adipose tissue thickness with ultrasound in men and women are presented in Tables 8 and 9, respectively. At the breast and buttocks sites, where caliper measurements are impractical or difficult in both men and women, the ultrasonic data showed relatively large means and SD of the differences for observer A but not for observer B. The breast and buttocks sites are of particular interest because caliper measurements cannot be made effectively at those sites. Reliability at the breast site was lower than that at most other sites in the men, but was relatively high at the buttocks. In the women, the CR for ultrasonic measurements at the breast and buttocks sites were 61.3% and 77.1%, respectively, for observer A and 77.0% and 82.7%, respectively, for observer B.

There were significant differences between observers in mean absolute intra-observer errors for some of the ultrasonic variables recorded. In each such case, the means were larger for observer A at triceps, subscapular, biceps, midaxillary, anterior thigh, and lateral calf sites in both sexes and at the paraumbilical site in women. Significant sex differences between mean intra-observer errors were present for ultrasonic measurements at the triceps, biceps, midaxillary, anterior thigh and lateral calf sites. In each case, the mean was larger for the women than for the men.

TABLE 7. Distribution Statistics for Intra- and Inter-Observer Differences for Bioelectric Resistance in Men and Women by Observers.

Ultrasound Site	N (pairs)	Mean[a] (mm)	SD (mm)	TE[b]	CV (%)	CR[c] (%)
Intra-Observer						
Observer A						
Men	96	6.1	4.9	5.5	1.2	98.1
Women	84	6.1	5.1	5.6	9.7	99.3
Observer B						
Men	87	5.9	4.8	5.4	1.2	98.0
Women	84	6.4	4.9	5.7	1.0	99.2
Inter-Observer						
Men	99	0.7	1.2	1.0	0.2	100.0
Women	85	0.9	2.6	1.9	0.3	99.9

a. Mean of absolute differences
b. Technical error of measurement
c. Coefficient of reliability

The ultrasonic measurements of subcutaneous adipose tissue thicknesses had mean inter-observer errors and SD values ranging from 1.1 to 2.2 mm with only small differences between the sexes (Table 10). The maximum differences for each site ranged from 4.7 to 12.6 mm in the men and from 4.2 to 9.5 mm in the women. The TE for the ultrasonic measurements were similar for the two sexes and ranged from 1.1 to 2.2 mm. The CV ranged from 22.1% to 36.2% in the men and from 19.7% to 32.0% in the women.

CR was low for the measurements of subcutaneous adipose tissue thickness with the EchoScan 1502 ultrasound machine with ranges of 26.2% to 63.6% for the men and a similar range for the women. There was little correspondence between the sexes in the ultrasound sites that had relatively high or relatively low reliability. CR tended to be relatively high for the midaxillary and lateral calf sites in the men and for the subscapular and buttocks sites in the women, while the sites with relatively low reliability were the breast and anterior thigh for the men and the triceps and lateral calf for the women.

The distributions for inter-observer errors differed significantly between the sexes for most sites. Larger errors were observed in women for triceps, biceps, midaxillary, anterior thigh, and lateral calf skinfolds, and ultrasonic measurements at the triceps and lateral calf sites. Larger errors were observed in men for ultrasonic measurements at the breast site, however, the magnitudes of these sex-associated differences were generally small.

TABLE 8. Distribution Statistics for Intra-Observer Differences for Ultrasonic Measures in Men by Observers.

Ultrasound Site	N (pairs)	Mean[a] (mm)	SD (mm)	TE[b]	CV (%)	CR[c] (%)
Observer A						
Triceps*	89	1.1	1.0	1.0	19.1	62.6
Subscapular*	89	1.2	1.0	1.1	19.0	69.3
Biceps*	89	1.0	1.0	1.0	28.0	64.3
Midaxillary*	89	1.1	1.0	1.1	20.4	68.5
Breast	89	1.6	1.5	1.6	24.8	60.9
Paraumbilical	88	1.5	1.3	1.4	22.2	67.1
Anterior Thigh*	89	1.2	1.3	1.2	21.1	71.4
Lateral Calf*	89	1.2	1.1	1.1	28.3	59.3
Buttocks	85	1.1	1.1	1.1	15.8	75.9
Observer B						
Triceps*	89	0.7	0.6	0.7	13.2	86.0
Subscapular*	89	0.8	0.8	0.8	15.8	81.2
Biceps*	89	0.5	0.5	0.5	17.4	84.8
Midaxillary*	89	0.8	0.7	0.8	15.1	85.7
Breast	89	1.2	1.2	1.2	22.0	73.3
Paraumbilical	88	1.3	1.4	1.4	21.6	82.0
Anterior Thigh*	89	0.8	0.8	0.8	15.0	80.9
Lateral Calf*	89	0.6	0.6	0.6	15.3	79.9
Buttocks	85	0.9	0.7	0.8	13.3	85.3

a. Mean of absolute differences
b. Technical error of measurement
c. Coefficient of reliability
*. Significant difference in mean values between observers ($P<0.05$).

Hypothesis 3

Anthropometry. Inter-observer errors were computed for more anthropometric and body composition variables than were intra-observer errors. Intra-observer errors were not important for measures of stature, weight, arm and calf circumferences, and the measures of body composition because the magnitudes of these measurements are very large compared to the magnitudes of their corresponding intra-observer errors. Intra-observer errors were, however, important for skinfold variables.

TABLE 9. Distribution Statistics for Intra-Observer Differences for Ultrasonic Measures in Women by Observers.

Ultrasound Site	N (pairs)	Mean[a] (mm)	SD (mm)	TE[b]	CV (%)	CR[c] (%)
Observer A						
Triceps*	83	1.9	1.7	1.8	27.4	41.6
Subscapular*	82	1.4	1.0	1.2	19.5	64.8
Biceps*	83	1.3	1.2	1.3	28.8	62.7
Midaxillary*	83	1.6	1.7	1.6	26.6	31.2
Breast	82	1.4	1.3	1.4	22.2	61.3
Paraumbilical*	82	1.7	1.5	1.6	23.4	47.3
Anterior Thigh*	82	1.6	1.5	1.6	17.5	61.7
Lateral Calf*	83	1.6	1.4	1.5	28.6	47.8
Buttocks	78	1.3	1.2	1.3	17.2	77.1
Observer B						
Triceps*	85	1.2	1.2	1.2	15.1	81.3
Subscapular*	84	0.8	0.7	0.7	11.8	85.4
Biceps*	85	0.7	0.7	0.7	15.8	79.7
Midaxillary*	85	1.0	0.9	0.9	15.3	71.2
Breast	84	1.1	1.1	1.1	19.4	77.0
Paraumbilical*	84	1.2	1.3	1.2	17.0	87.7
Anterior Thigh*	84	1.1	1.5	1.3	13.9	65.0
Lateral Calf*	85	0.9	0.9	0.9	15.0	80.7
Buttocks	80	1.1	1.2	1.2	16.2	82.7

a. Mean of absolute differences
b. Technical error of measurement
c. Coefficient of reliability
*. Significant difference in mean values between observers ($P<0.05$).

Data for intra-observer errors for the skinfold measurements in men are presented for each observer in Table 11, and the corresponding data for women are presented in Table 12. Intra-observer errors are available for the skinfold measurements only. The means were less than 1.0 mm for all skinfolds in men with the exception of the subscapular and paraumbilical skinfolds. The SD values were close to 1.0 mm with the exception of those for the paraumbilical skinfold which were 1.5 and 1.8 mm for observers A and B, respectively. For both observers, the differences were particularly small for the biceps and lateral calf skinfolds.

TABLE 10. Distribution Statistics and Reliability for Ultrasonic Inter-Observer Differences.

Ultrasound Site	N (pairs)	Mean[a] (mm)	SD (mm)	TE[b]	CV (%)	CR[c] (%)
Men						
Triceps*†	91	1.3	1.1	1.2	22.1	52.7
Subscapular†	91	1.4	1.3	1.4	25.2	54.8
Biceps†	91	1.2	1.2	1.2	35.4	46.1
Midaxillary†	91	1.2	1.2	1.2	23.6	63.6
Breast*	91	2.2	2.2	2.2	36.2	26.2
Paraumbilical	90	2.1	2.0	2.0	30.5	51.3
Anterior Thigh†	91	1.4	1.4	1.4	23.8	38.5
Lateral Calf*†	91	1.1	1.0	1.1	28.0	56.0
Buttocks†	91	1.7	1.2	1.5	23.5	53.6
Women						
Triceps*	84	2.0	2.1	2.0	27.4	26.8
Subscapular†	83	1.2	1.3	1.3	19.8	65.1
Biceps†	84	1.3	1.3	1.3	29.8	61.4
Midaxillary†	84	1.4	1.1	1.3	21.4	53.5
Breast*†	83	1.5	1.3	1.4	24.3	57.4
Paraumbilical	83	1.8	1.8	1.8	25.0	56.4
Anterior Thigh	83	1.7	2.0	1.8	19.7	41.1
Lateral Calf*	84	2.0	1.6	1.8	32.0	39.3
Buttocks	79	1.8	1.7	1.7	23.7	62.1

a. Mean absolute differences
b. Technical error of measurement
c. Coefficient of reliability
†. Positively skewed distribution at $\alpha = 0.05$
*. Significant sex difference in mean values ($P<0.05$)

The relatively small differences for the biceps and lateral calf skinfolds and relatively large differences for the paraumbilical and subscapular skinfolds were in agreement with the values of the technical errors. The CV, which take the means into account, were relatively small for the lateral calf skinfold and relatively large for the biceps skinfold. For all skinfolds, reliability, determined from a nested analysis of variance with a random effects model, was so high (92.4% to 98.9%) that it was not desirable to differentiate among sites on this basis. The means and SD were generally about 1.0 mm larger for women than those for men. The largest means were those for the paraumbilical skinfold, while the smallest were for the subscapular skinfold (observer A) or the lateral calf skinfold (observer B).

TABLE 11. Distribution Statistics for Intra-Observer Differences for Skinfold Measurements in Men by Observers.

Ultrasound Site	N (pairs)	Mean[a] (mm)	SD (mm)	TE[b]	CV (%)	CR[c] (%)
Observer A						
Triceps	98	0.8	0.8	0.8	7.8	97.2
Subscapular	98	0.8	1.0	0.9	6.7	97.2
Biceps*	98	0.7	0.9	0.8	17.3	93.1
Midaxillary	98	0.8	1.0	0.9	9.5	97.8
Paraumbilical	97	1.2	1.5	1.4	8.4	98.9
Anterior Thigh	96	0.9	1.1	1.0	8.6	96.4
Lateral Calf	95	0.4	0.4	0.4	5.3	98.8
Observer B						
Triceps	89	0.7	1.0	0.8	7.8	97.3
Subscapular	89	1.0	1.2	1.1	8.9	96.7
Biceps*	89	0.4	0.7	0.6	12.7	92.4
Midaxillary	89	0.6	0.8	0.7	7.2	97.8
Paraumbilical	88	1.4	1.8	1.6	9.6	97.5
Anterior Thigh	87	0.8	1.1	0.9	8.4	97.1
Lateral Calf	87	0.5	0.6	0.6	6.7	97.5

a. Mean of absolute differences
b. Technical error of measurement
c. Coefficient of reliability
*. Significant difference in mean values between observers ($P<0.05$).

The TE of the skinfold measurements in the women tended to be large for the paraumbilical skinfold for each observer and were particularly small for the subscapular skinfold (observer A) and for the lateral calf skinfold (observer B). The CV were large for the biceps skinfold and small for the anterior thigh skinfold. The CR of the skinfold measurements varied from 88.3% to 97.9% among sites.

TABLE 12. Distribution Statistics for Intra-Observer Differences for Skinfold Measurements in Women by Observers.

Ultrasound Site	N (pairs)	Mean[a] (mm)	SD (mm)	TE[b]	CV (%)	CR[c] (%)
Observer A						
Triceps	85	1.2	1.4	1.3	7.0	96.0
Subscapular	84	1.0	1.1	1.1	8.3	96.9
Biceps	84	1.1	1.3	1.2	15.0	93.7
Midaxillary	84	1.2	1.4	1.3	11.5	92.6
Paraumbilical	83	1.7	1.7	1.7	7.9	96.6
Anterio Thigh	71	1.7	1.4	1.6	6.1	95.1
Lateral Calf*	77	1.3	1.8	1.5	10.8	88.3
Observer B						
Triceps	85	1.1	1.0	1.0	5.4	96.8
Subscapular	84	1.0	1.0	1.0	7.5	97.3
Biceps	85	0.8	1.0	0.9	12.0	94.5
Midaxillary	84	0.9	1.0	1.0	9.1	96.5
Paraumbilical	84	1.9	1.9	1.9	8.2	94.5
Anterior Thigh	71	1.5	1.6	1.5	6.1	95.5
Lateral Calf*	76	0.7	0.8	0.7	4.8	97.9

a. Mean of absolute differences
b. Technical error of measurement
c. Coefficient of reliability
*. Significant difference in mean values between observers ($P<0.05$).

Inter-observer differences for underwater weights and RV are presented for men and women in Tables 13 and 14, respectively. In each sex, mean absolute differences, SD, and CV for each body composition measurement were very small, while the CR were 97% or greater.

The inter-observer errors for the anthropometric variables are presented in Tables 13 and 14 also. For both men and women, the errors for stature, weight, and arm and calf circumference were very small. The inter-observer CR was 99% or greater for each of these measurements. The skinfolds had mean inter-observer errors that ranged from 0.8 to 1.4 mm in men (SD 0.9 to 2.0 mm) and from 1.4 to 2.3 mm in women (SD 1.4 to 2.1 mm). The inter-observer differences were relatively large for the paraumbilical skinfolds in each sex and for measurements at the subscapular site in men. Relatively small inter-observer mean differences occurred for the biceps and midaxillary sites in each sex and for the lateral calf site in men. CR was consistent among sites for the skinfold measurements. The CR of skinfolds at particular sites ranged from 87.7% to 96.3% in the men with a similar range for the women. CR was particularly high for the midaxillary and paraumbilical sites and somewhat low for the biceps site in each sex.

TABLE 13. Distribution Statistics and Reliability for Inter-Observer Differences in Men.

Variables	N (pairs)	Mean[a]	SD	TE[b]	CV (%)	CR[c] (%)
Body Composition						
Underwater Wt† (kg)	94	0.1	0.1	0.1	1.9	98.8
Residual Lung Volume (L)	99	0.1	0.1	0.1	4.9	97.8
Anthropometry						
Stature† (cm)	100	0.2	0.2	0.2	0.1	99.8
Weight in Air† (kg)	94	0.0	0.0	0.0	0.05	100.0
Arm Circumference† (cm)	100	0.1	0.1	0.2	0.4	99.1
Calf Circumference† (cm)	91	0.1	0.1	0.1	0.3	99.9
Skinfolds (mm)						
Triceps*†	91	1.1	1.2	1.2	11.1	95.5
Subscapular†	91	1.4	1.7	1.5	12.8	94.1
Biceps*†	91	0.8	1.0	0.9	18.5	87.7
Midaxillary*†	91	0.8	1.1	1.0	10.4	96.0
Paraumbilical	90	1.8	2.0	1.9	11.5	96.3
Anterior Thigh*†	89	1.2	1.4	1.3	11.0	95.1
Lateral Calf*†	89	0.8	0.9	0.9	10.7	93.9

a. Mean absolute differences
b. Technical error
c. Coefficient of reliability
†. Positively skewed distribution at $\alpha = 0.05$
*. Significant sex difference in mean values ($P<0.05$)

Hypothesis 4

Machine/Observer Interactions. Tests for the presence of machine by observer interactions were conducted for the Bioelectric Impedance Analyzer and the EchoScan 1502 ultrasound machine only. Analyses of variance were performed on machine and observer differences using a balanced design with the same number of observations (N = 8) for each participant. Each participant whose data were included in these analyses had measurements by observer A and by observer B using machine 1 and machine 2 and these measurements were repeated. Analyses of variance with a 3-factor factorial mixed effects model was performed. The participants were considered to contribute a random effect, and the observers and machines were considered to contribute fixed effects. There were no significant main effects due to either the impedance or ultrasound machines, but there were significant effects due to observer for biceps, breast, and buttocks adipose tissue thicknesses measured with ultrasound. Also, there were significant machine-observer interactions for ultrasonic measurements of adipose tissue thicknesses at the midaxillary, anterior thigh, and lateral calf sites. These results are presented in Table 15.

TABLE 14. Distribution Statistics and Reliability for Inter-Observer Differences in Women.

Variables	N (pairs)	Mean[a]	SD	TE[b]	CV (%)	CR[c] (%)
Body Composition						
Underwater Wt† (kg)	84	0.1	0.1	0.1	4.00	97.0
Residual Lung Volume (L)	86	0.0	0.0	0.0	4.10	98.3
Anthropometry						
Stature† (cm)	86	0.2	0.2	0.2	0.1	99.9
Weight in Air† (kg)	85	0.0	0.0	0.0	0.05	100.0
Arm Circumference† (cm)	86	0.1	0.1	0.1	0.4	99.9
Calf Circumference† (cm)	84	0.1	0.1	0.1	0.3	99.9
Skinfolds (mm)						
Triceps*†	84	1.6	1.4	1.5	8.2	93.4
Subscapular	83	1.6	1.6	1.6	11.6	93.5
Biceps*†	84	1.6	1.8	1.7	21.2	85.0
Midaxillary*†	83	1.4	1.4	1.4	12.5	94.7
Paraumbilical	83	2.3	2.0	2.1	9.4	94.6
Anterior Thigh*	70	2.1	2.1	2.1	8.3	93.6
Lateral Calf*†	76	1.6	1.4	1.5	10.1	89.9

a. Mean = Mean of absolute differences
b. Technical error
c. Coefficient of reliability
†. Positively skewed distribution at $\alpha = 0.05$
*. Significant sex difference in mean values ($P<0.05$)

Discussion

For mean absolute intra- and inter-observer differences, SD, and TE, there are small differences between corresponding skinfold caliper and ultrasonic measurements for men or women. However, the relative degree of difference in intra- and inter-observer errors between these two methods was clearer in the values for CV and CR, and more so for the inter- than the intra-observer errors. For both intra- and inter-observer errors, the CV values for the skinfold caliper measurements were only about half the values of the CVs for corresponding ultrasonic measurements. Almost the opposite was true for the more important CR. In each sex, the intra-observer CR for the ultrasonic measurements were about 10 to 35 percentage points below corresponding values for the skinfold calipers, but for interobserver CR values the differences between corresponding ultrasonic and skinfold caliper measurements increased to a difference of 30 to 60 percent. The poor inter-observer reliability for the ultrasonic measurements was reflected in the frequency of significant differences between observers in their intra-observer differences.

TABLE 15. Summary of Findings from Analysis of Variance, P-values for the Main Effects and Interaction Effects of Machine and Observer.

Ultrasound Sites	Effects Machine	 Observer	 Machine by Observer
Triceps	0.061	0.108	0.787
Subscapular	0.428	0.867	0.079
Biceps	0.547	0.002**	0.396
Midaxillary	0.290	0.440	0.032*
Breast	0.454	0.001**	0.608
Paraumbilical	0.254	0.078	0.074
Anterior Thigh	0.239	0.470	0.029*
Lateral Calf	0.321	0.632	0.012*
Buttocks	0.607	0.040*	0.113

* $P < 0.05$; ** $P < 0.01$

LATERALITY

Hypothesis

To determine if there were lateral differences in the values for a measurement within individuals or effects due to handedness, the following hypothesis was tested:

There are no differences in the mean values of corresponding measurements from the right and left sides of the body for bioelectric impedance, arm, and calf circumferences, or skinfold caliper and ultrasonic measures of subcutaneous adipose tissue thickness at the triceps, subscapular, biceps, midaxillary paraumbilical, anterior thigh, and lateral calf body sites.

Sample and Methods

Sample

The sample size differed slightly depending upon the kind of measurements taken. In general, the sample was a randomly selected from the sample of 177 healthy young adults described on page 23-24. All these participants were questioned about handedness with reference to strenuous physical activity. The anthropometric and ultrasonic measurements were recorded from both the right and left sides of the body in samples of 50 randomly selected participants for the anthropometric measurements and of 42 participants for the ultrasonic measurements. Thirty-four participants were randomly selected for both right and left side measures of bioelectric resistance. Since these participants were a randomly selected subsample of the sample described on pages 23-24, descriptive statistics will not be presented.

Methods

The methods used to collect the anthropometric, ultrasonic and bioelectric resistance data from the left side of the body were the same as those used to collect corresponding measurements from the right side of the body. The methods are described in Appendix B. All measures were taken by two observers working independently.

Results and Discussion

Results

Eighty-four percent of the participants were right-handed (80 men, 68 women), 12% were left-handed (7 men, 15 women) and 4% were ambidextrous (6 men, 1 woman).

Because so few participants were left-handed or ambidextrous, the analysis was restricted to the right-handed group. The possibility that there might be an effect due to handedness was tested in right-handed participants combining data for the two sexes using a paired t-test. The only lateral difference affected by handedness was the biceps skinfold thickness which was significantly smaller on the right than on the left in right-handed participants, regardless of the observer. However, there were some observer effects, with significant positive differences (right > left) for arm circumference and triceps (observer A); paraumbilical and lateral calf skinfolds (observer B) and significant negative effects (right < left) for triceps (observer A) and anterior thigh skinfolds (observer B), and for midaxillary (observer A) and anterior thigh (observer B) ultrasonic measurements. Except for biceps skinfold values, there were no significant lateral differences associated with handedness for the measurements recorded.

Discussion

Since the results of paired t-tests for corresponding right and left measurements were not different from zero, it was concluded that significant lateral effects were absent in the group tested. Also, there were no effects due to handedness except for the biceps skinfold, which was smaller on the right side in right-handed participants.

SUMMARY AND IMPLICATIONS FOR USE OF NEW EQUIPMENT

Bioelectric Impedance Analyzer

The intra-machine errors were extremely small with mean absolute differences accounting for only about 0.2% of the observed mean values for individuals. Similar high intra-machine reliability has been reported by others (113). The intra-machine differences also showed excellent results with CR estimates of 99.5% or more for each of two observers. An analysis of variance did not show significant main effects of machine or a significant machine by machine interaction. The intra- and inter-observer differences were also very small, accounting for about 0.2% and 1.2% of the observed mean values for individuals. The CR for both types of error was excellent at 98% or higher. These results are in general agreement with similar tests of CR of the Bioelectrical Impedance

Analyzer reported for smaller samples with less complete sets of data (99,110-113,124).

EchoScan 1502 Ultrasound Equipment

The measurement of subcutaneous adipose tissue thickness with ultrasonic equipment has considerable appeal because this method avoids the errors caused by individual differences in the compressibility of subcutaneous adipose tissue (84). The use of other portable ultrasound equipment has not been satisfactory because of poor reliability and limited accuracy (82,83). The EchoScan 1502 records to 0.1 mm, but in the present analyses intra-observer reliability was considerably less than that of skinfold calipers. In comparison with skinfold calipers, the inter-observer CR was even worse. The present observers have previous experience with similar ultrasonic equipment and took great care to obtain the best possible data with the EchoScan equipment.

Anthropometry

The intra- and inter-observer errors for each of the anthropometric variables were small and the CR was high. These findings are consistent with reports of reliability from other studies by the same personnel with participants ranging in age from childhood to old age (30,118,125,126). These replicability data are better than those reported for corresponding measurements by others (127-133).

Lateral Differences

There were no significant lateral differences that would affect the bioelectric impedance, the ultrasonic, or the anthropometric data. The only consistent difference was a smaller biceps skinfold thickness on the right side in right-handed participants. Other right-left differences or effects of handedness were due to differences between observers.

Summary

Findings from the present study show that the Bioelectric Impedance Analyzer is a very reliable instrument with small observer errors. However, the EchoScan 1502 ultrasound equipment is not reliable even in the hands of trained and experienced technicians.

VALIDITY OF BIOELECTRIC IMPEDANCE

RATIONALE

The Bioelectric Impedance Analyzer is accurate and reliable, but an important question is its validity in estimating body composition variables. As stated earlier, impedance (Z) is directly proportional to the length of the conductor and inversely proportional to its cross-sectional area (Z = Length/Area). Also, the volume (V) of a conductor is equal to its length times its cross-sectional area (V = Length x Area). Substitution of the latter in the formula, Z = Length/Area for A, changes the formula to $Z = \text{Length}^2/V$ or $V = \text{Length}^2/Z$; the volume of a conductor is equal to its length squared divided by impedance. In biological terms, this would mean that the volume of lean body mass is approximately equal to stature squared divided by the value of bioelectric impedance. As noted previously, impedance is equal to the square root of the sum of the squares of resistance and reactance. In the present study, only bioelectric resistance was measured because the reactance of the human body is small, and the value of bioelectric resistance is highly correlated with bioelectric impedance (102).

The validity of bioelectric impedance will be tested by comparing measurements of $\text{stature}^2/\text{resistance}$ against estimates of body composition determined from underwater weighing. Underwater weighing is the reference method against which all techniques of measuring body composition are compared. If bioelectric impedance is a valid method of estimating body composition, then $\text{stature}^2/\text{resistance}$ will be highly correlated with measures of fat-free mass and total and percent body fat determined from underwater weighing. Also, bioelectric impedance measures may significantly improve the prediction of body composition variables from anthropometric data. Because of known differences in body composition between men and women and between blacks and whites, tests of validity were conducted separately in each group.

VALIDATION

Hypotheses

The validity of bioelectric impedance was tested with the following hypotheses:

1. Bioelectric resistance is not associated with stature, stature^2, weight, upper arm circumference or calf circumference.

2. Bioelectric resistance used in combination with some or all of the following anthropometric variables, including stature, stature^2, weight, upper arm circumference, and calf circumference is not significantly correlated with BD, FFM, or TBF and %BF as determined by underwater weighing.

Samples and Methods

Sample

This sample consisted of the 177 healthy young adults who each participated in measures of underwater weighing, anthropometry, residual volume, and bioelectric resistance. Within this sample were 78 white men, 15 black men, 75 white women, and 9 black women. A complete description of this sample is presented on page 23.

Methods

A complete description of the methods is presented on pages 17-19 and in Appendix B. Briefly, ten underwater weighings were recorded for each participant by each of two observers working independently. RV was measured on land to the nearest 0.1 L by a nitrogen washout method. The following anthropometric variables were recorded once by each of two observers independently: stature, weight, and arm and calf circumferences. The following skinfolds were recorded twice by each of two observers independently: triceps, biceps, subscapular, midaxillary, paraumbilical, anterior thigh, and lateral calf. Bioelectric resistance was measured with an RJL Systems Model BIA-101 Analyzer as described on page 16 and in Appendix B. Bioelectric resistance was measured twice on the right side of the body of each participant by each of two observers working independently. All measurements were collected from each participant on the same day.

Results and Discussion

Results

Descriptive statistics for the underwater weighing, RV, anthropometry, and bioelectric impedance testing are presented in Appendix D. Briefly, the men were, on the average, taller, heavier, and had greater BD, FFM, RV, and body circumference values than the women. The women had greater amounts of TBF and %BF, thicker subcutaneous adipose tissue, and larger bioelectric resistance values than the men. Mean values of stature and weight for these men and women are greater than those recorded in recent U.S. Army anthropometric surveys (96).

Hypothesis 1

The results for the test of Hypothesis 1 are presented in Table 16. The correlation coefficients for stature^2 have been omitted from this table because they were identical to those for stature. Except for stature, the correlation coefficients are all negative and highly significant. The lack of significance for some variables in the black women reflects the small sample size.

TABLE 16. Correlations Between Bioelectric Resistance and Anthropometric Variables.

Group	N	Stature	Weight	Arm Circ.	Calf Circ.
White Men	78	0.16	-0.56**	-0.68**	-0.59**
Black Men	15	-0.15	-0.72**	-0.70**	-0.86**
White Women	75	0.08	-0.58**	-0.62**	-0.60**
Black Women	7	0.0	-0.29	-0.38	-0.82*

* $0.01 \leq P < 0.05$; ** $P < 0.01$

Hypothesis 2

For Hypothesis 2, regression equations were formulated using stature^2/resistance as a forced regressor and stature, weight, upper arm circumference, calf circumference, and age as potential regressors to predict body composition variables. Maximum R^2 improvement methods (14) were applied to the observed data to select the best predictive model.

As a preliminary step, BD was correlated with stature^2/resistance, stature, weight in air, arm and calf circumference, and age in blacks and whites combined as shown in Table 17. Correlations were not calculated between BD and stature^2 because the coefficients would necessarily be the same as those between BD and stature. The correlations with stature^2/resistance, stature, and age were not significant, but all the other correlations had significant negative values.

TABLE 17. Correlations Between Body Density and Stature^2/Resistance, Stature, Weight in Air, Arm Circumference, Calf Circumference, and Age for Blacks and Whites Combined.

Variables	Body Density			
	Men		Women	
	N	r	N	r
Stature^2/Resistance (cm^2/ohm)	94	-0.18	82	-0.04
Stature (cm)	94	-0.13	83	0.18
Weight in air (kg)	94	-0.61*	83	-0.57*
Arm Circumference (cm)	94	-0.50*	83	-0.65*
Calf Circumference (cm)	94	-0.56*	84	-0.59*
Age (years)	94	-0.10	84	-0.14

* $P < 0.05$

The best models for predicting BD, %BF, TBF, or FFM, excluding stature^2/ resistance, for men and women were selected by a stepwise regression procedure and by maximum R^2 regressions. The results were almost identical between the stepwise and maximum R^2 regression procedures; therefore, only the latter are reported in Table 18. The anthropometric variables retained were the same for all four regressions for men (stature, weight, arm circumference). The regressions to predict BD or %BF had adjusted R^2 values of 0.40. The same variables were also used to predict TBF, and the adjusted R^2 value was 0.63. The equation to estimate FFM had an adjusted R^2 value of 0.73 and a RMSE of 3.94 kg that was necessarily equivalent to that for TBF.

Sets of corresponding regression analyses that predicted BD, %BF, TBF, or FFM were computed for women, without including stature^2/resistance as an independent variable. The independent variables retained for the prediction of %BF and BD were calf circumference and stature^2. The regression equation to predict TBF retained weight and stature^2 as independent variables, and the adjusted R^2 value was 0.74. When a similar analysis was made with FFM as the dependent variable, the independent variables retained were weight and stature^2 only with an adjusted R^2 value of 0.60. These results are presented in Table 18.

TABLE 18. Adjusted R^2 and Root Mean Squared Error (RMSE) for the Prediction of Body Composition Variables from Anthropometry in Men and Women for Blacks and Whites Combined.

Dependent Variable	N	Adjusted R^2	RMSE
Men			
Body Density	93	0.40	0.011 gm/cm^3
Percent Body Fat	93	0.40	4.90 %
Total Body Fat	93	0.63	3.94 kg
Fat Free Mass	93	0.73	3.94 kg
Women			
Body Density	80	0.48	0.011 gm/cm^3
Percent Body Fat	80	0.49	5.00 %
Total Body Fat	80	0.74	3.30 kg
Fat Free Mass	80	0.60	3.30 kg

When stature^2/resistance was included in the regressions for predicting BD, %BF, TBF, or FFM, the selection and order of the independent variables was changed for men and women. BD in men was predicted from stature^2/resistance, weight, and calf circumference with an adjusted R^2 value of 0.60. For the prediction of TBF or FFM, the same independent variables were retained with adjusted R^2 values of 0.76 and 0.83, respectively. These results are presented in Table 19.

When corresponding regression analyses that included stature^2/resistance as an independent variable were performed for women, the order in which the independent variables entered was the same for BD as for %BF. These variables were weight, calf and arm circumferences, and age. The adjusted R^2 value was 0.68 for BD and 0.69 for %BF (Table 19). In the regression equations with TBF or FFM as the dependent variable, the same independent variables were retained for each. Stature entered into the model as the third variable in the prediction of TBF and as the second variable in the prediction of FFM. In each case, stature was subsequently removed from the model based on the results of partial F-tests. The multiple regression equation for TBF had an adjusted R^2 value of 0.84, while that for FFM had an adjusted R^2 value of 0.75. Specific equations for the prediction of FFM, %BF, or TBF from anthropometry and stature^2/resistance are in Appendix C.

TABLE 19. Adjusted R^2 and Root Mean Squared Error (RMSE) for the Prediction of Body Composition Variables from Anthropometry and Stature^2/Resistance in Men and Women for Blacks and Whites Combined.

Dependent Variable	N	Adjusted R^2	RMSE
Men			
Body Density	93	0.60	0.009 gm/cm^3
Percent Body Fat	93	0.60	4.00 %
Total Body Fat	93	0.76	3.14 kg
Fat Free Mass	93	0.83	3.14 kg
Women			
Body Density	79	0.68	0.008 gm/cm^3
Percent Body Fat	79	0.69	3.90 %
Total Body Fat	79	0.84	2.61 kg
Fat Free Mass	79	0.75	2.61 kg

Discussion

The first step in analyzing the validity of the bioelectric resistance measurements is to determine if its relationship to anthropometric variables was similar to that reported for body density. The anthropometric variables selected (weight, and arm and calf circumferences) are negatively correlated with body density and positively correlated with %BF and TBF in adults (9,18,127,134-135). A similar relationship between stature^2/resistance and weight, arm circumference, and calf circumference is confirmed in the present study within race and sex-specific groups.

More direct tests of the validity of bioelectric resistance measurements were made by relating combinations of "stature^2/resistance plus anthropometric variables" to BD, %BF, TBF, or FFM from underwater weighing. The best equations for men were those including stature^2/resistance, weight, and calf circumference. The RMSE values were 0.009 gm/cm^3 for BD, 4.002% for %BF, and 3.143 kg for TBF and for FFM. The analyses for women indicated that the best equations included stature^2/resistance, weight, calf circumference, and age. The RMSE values were 0.008 gm/cm^3 for BD, 3.893% for %BF, and 2.612 kg for TBF and FFM in women. These RMSE values were similar to those when the best combinations of stature^2/resistance and skinfolds were used.

These findings can be compared with the SEE of 5.08% and 3.06% reported for estimates of %BF in a group of somewhat obese adults, aged 17-59 years (68). The larger value was obtained when the equation of the manufacturer, RJL Systems, was applied, and the smaller was obtained with a study-specific equation using stature^2/resistance as the independent variable. A value of 6.04% for the SEE of %BF in lean young men, using stature^2/resistance and the regression formula provided by the manufacturer has also been reported (124). Others (113), have reported a SEE for FFM of 4.43 kg when stature^2/resistance was used to predict FFM employing the equation supplied by the manufacturer. In the same study (113), an equation that included weight was derived, and the SEE for FFM decreased to 3.06 kg. Lukaski et al. (99) reported a value of 2.61 kg for the SEE of fat-free mass using their own regression equation that employed stature^2/resistance as the independent variable. When this equation was applied to a different sample, a SEE of 3.06 kg was obtained for TBF (124). In each of these studies, the "direct" measures of body composition were obtained from underwater weighing, except that of Lukaski et al. (99), who employed TBW from deuterium oxide D_2O.

This approach to the validation of bioelectric impedance as an index of body composition is based on the assumptions that BD can be measured without error by underwater weighing and that Siri's equation (20) accurately estimates %BF from BD after which TBF and FFM can be calculated mathematically. The accuracy of measurement of BD depends almost entirely on the measurement of underwater weight and of RV. There is convincing evidence that underwater weighing is highly reliable (20-21, 28-30, 32-36, 128, 136), as was the case in the present study where the inter-observer differences were very small and the reliability high (men 98.8%; women 97.0%). RV measurements are also highly reliable (137). In the present study, the reliability of RV was about 98% for men and women. However, if the measurement of BD were completely free of error, the prediction of %BF from BD would still have an error of about $\pm$ 2.5% because the equations used are far from ideal (13). Siri's equation (20) to predict %BF from BD yields results similar to those from use of the equation of Brozek et al. (21) except at low BD values (implying high values for %BF) where Lohman (13) has demonstrated that predictions from Siri's equation are higher than those from the Brozek equation. These equations are appropriate for healthy young white men (138), but they are inappropriate for groups in which FFM is more dense than the value assumed by Siri (20). This occurs in black men and leads to underestimation of %BF (22). An opposite tendency (less dense FFM; overestimation of %BF) occurs in women (139); and a separate equation for women has been developed (23,139).

Summary

Estimates of %BF from underwater weighing have an SEE of about 2.5% (13). When values from underwater weighing are used as criteria, 2.5% becomes the irreducible minimum for the errors of estimation. Consequently, the finding that the RMSE of the estimate of %BF from stature^2/resistance plus simple anthropometry is 4.00% for men and 3.90% for women is a good result. The general conclusion is that stature^2/resistance plus anthropometry provides a more accurate estimate of body composition than anthropometry alone. This is supported by published reports (10, 68, 140, 141).

RACIAL DIFFERENCES

Hypotheses

The possibility of racial differences in measures of bioelectric impedance was tested with the following hypothesis:

> The differences between predictions of body composition from bioelectric impedance and anthropometry and from underwater weighing do not differ systematically between whites and blacks.

Sample and Methods

Sample

The sample consisted of the 177 healthy young adults who each participated in measures of underwater weighing, anthropometry, residual volume, and bioelectric resistance described on pages 23-24. Within this sample, there were

78 white men, 15 black men, 75 white women and 9 black women. Blacks comprised 14.3% of the total sample.

Methods

The methods are the same as those used for this sample of participants in the validation study. A complete description of these methods is presented on pages 16–17 and in Appendix B. Briefly, underwater weight, RV, bioelectric resistance, and the following anthropometric data were obtained from each participant: stature, weight, arm and calf circumferences, and triceps, biceps, subscapular, midaxillary, paraumbilical, anterior thigh, and lateral calf skinfolds. All measurements were collected from each participant on the same day.

Results and Discussion

Results

Racial differences were tested within each sex using the best combinations of stature^2/resistance and anthropometry from the stepwise regressions selected in the validation study. These prediction equations were influenced to a greater extent by the inter-relationships among the variables in the white participants than in the black participants because blacks comprised only 14% of the sample. Therefore, one might expect differences between corresponding body composition variables (underwater weighing vs prediction equations) to be larger for black participants than for white participants.

In the men, mean differences in corresponding values of BD and FFM predicted from stature^2/resistance plus anthropometry and from underwater weighing were significantly larger for blacks than whites (Table 20). For %BF and TBF, these differences were reversed, with blacks having smaller mean differences than whites.

Corresponding differences for women were not tested for significance because there were so few black women in the sample. The directions of the differences for the women were opposite those for the men, and the differences in mean values were smaller than those for the men.

TABLE 20. Mean Differences Between Corresponding Body Composition Variables in Whites and Blacks Predicted from Stature^2/Resistance plus Anthropometry and from Underwater Weighing.

Groups	BD	%BF	TBF	FFM
	Mean Differences+			
	gm/cm^3	%	kg	kg
Men				
Whites	-0.0010*	0.47**	0.41**	-0.41**
Blacks	0.0054*	-2.42**	-2.15**	2.15**
Women				
Whites	0.0003	-0.14	-0.04	-0.68
Blacks	-0.0039	1.73	0.50	0.56

* $0.01 < P < 0.05$
** $P < 0.01$
\+ Significance Calculated as White versus Black

Discussion

Comparisons have been made between blacks and whites in mean differences between body composition predictions from stature^2/resistance plus anthropometry and estimates from underwater weighing. The present findings show that predictions of body composition variables from stature^2/resistance plus anthropometry for black men will be altered to make the mean estimates equivalent to the values from underwater weighing. This implies separate regression equations for blacks and for whites are necessary. It is expected that the RMSE for these equations would be smaller than those for the present equations. Corresponding findings for the women showed smaller differences with opposite signs between blacks and whites, but the small number of black women did not provide robust statistical tests.

SUMMARY

Contrasts of the mean differences between body composition estimates derived from bioelectric impedance and those derived from BD indicate that the equations derived in this study are less accurate (relative to BD) for black men than for white men. Sample sizes were too small to test the accuracy for black women, but similar results would be anticipated. It is recommended that separate predictive equations be derived for black men and women, and that bioelectric impedance be validated on other racial/ethnic groups.

EFFECTS OF PHYSIOLOGICAL FACTORS

RATIONALE

Body composition is affected by physiological factors, and these factors could also affect measures of bioelectric impedance. Normal day-to-day fluctuations or differences between individuals in physiological variables do not produce significant changes in body composition, but they could produce changes in measures of bioelectric impedance that might affect its reliability and validity. For example, it is possible that diurnal variations in levels of hydration and electrolyte concentrations could affect the conductivity of the body, thus significantly altering bioelectric resistance values. Diet and exercise may also affect measures of bioelectric resistance. If the level of food and drink or the level of exercise were sufficiently large or occurred close to the time of examination, then changes in the level of body hydration, electrolyte balance, and mass could alter the conductivity of the body. In addition, the use of pharmacological agents and the timing of the menstrual cycle in women could produce spurious readings in measures of bioelectric resistance.

In order to test for any possible physiological effects on bioelectric impedance, three tests were designed. The first looked for the occurrence of diurnal variation in repeated measures of resistance. The second tested for possible effects of diet or exercise, and the third documented changes in bioelectric resistance during the menstrual cycle of women who were taking oral contraceptives and in women who were not taking oral contraceptives.

DIURNAL VARIATION

Hypothesis

The following hypothesis was used to test for diurnal variation in relation to bioelectric resistance measurements:

> There is no diurnal variation in bioelectric resistance measures recorded during the daytime.

Sample and Methods

Sample

This sample consisted of a separate group of four healthy young adults (two white men; two white women). The ages, statures and weights of these participants are presented in Table 21.

TABLE 21. Ages, Statures, and Weights of the Diurnal Variation Sample.

	Age	Stature	Weight
Men			
#1	23.9 years	175.7 cm	78.9 kg
#2	21.9 years	185.7 cm	58.3 kg
Women			
#3	20.4 years	168.4 cm	53.6 kg
#4	24.5 years	152.4 cm	49.7 kg

Methods

Nine measures of bioelectric resistance were recorded during a single day from each participant on the hour, starting at 0900 hours. Resistance was measured once by a single observer on the right side of each participant. The body locations for the attachment of the electrodes were the same as those described on page 16 and in Appendix B. During each resistance measurement, the arms rested by the sides of the participant's body and the medial malleoli were 25 cm apart. Each participant wore jeans.

During the one-hour intervals between the repeated resistance measurements, participants were free to come and go as they wished. Over the 8-hour period of data collection, each participant kept a record of the times and amounts of all food and drink consumed and of body eliminations.

Results and Discussion

Data were collected from two men and two women at each hour from 0900 to 1700 hours (Figure 2, page 55). A linear regression model was used to relate the

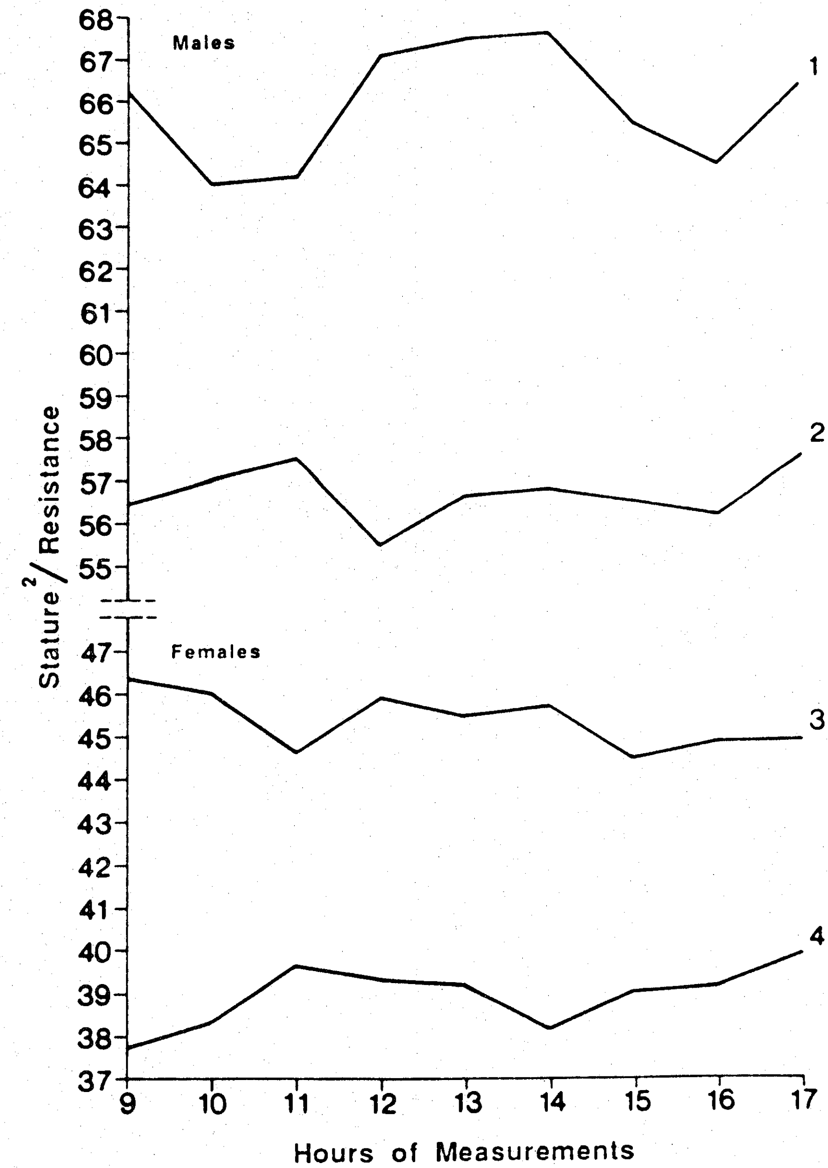

Figure 2. Hourly values of stature^2/resistance for two men and two women between 0900 and 1700 hours.

resistance values to time of day for each participant, using the means of two observations for each resistance value. These results are presented in Table 22. As expected, the intercepts differed significantly from zero, but the slopes did not differ significantly from zero. The test for autocorrelation was non-significant; consequently, there was no need for a non-linear model. These results indicate that diurnal variation does not affect measures of bioelectric impedance.

TABLE 22. Test for Diurnal Variation in the Serial Resistance Data: Regression of Resistance Versus Time of Day Within Participant.

Participant Nos.	Independent Variable	Regression Coefficients	t Statistics for HO:Coefficient =0	P Value	Auto-correlation
1	Intercept	607.22	84.27	< 0.001	
	Time of Day	-2.27	-1.77	0.120	NS[a]
2	Intercept	572.83	110.47	< 0.001	
	Time of Day	-0.30	-0.33	0.754	NS[a]
3	Intercept	613.78	111.88	< 0.001	
	Time of Day	2.13	2.19	0.065	NS[a]
4	Intercept	472.00	61.17	< 0.001	
	Time of Day	-0.73	-0.54	0.609	NS[a]

[a] NS = Nonsignificant at $\alpha = 0.05$; Durbin-Watson Test

A similar analysis was made of the cross-sectional bioelectric resistance data from the larger sample of the 177 participants described earlier on pages 23-24 in relation to the time of day at which these data were collected. Within each sex, the intercepts were significantly different from zero, but the slopes did not differ from zero which indicated the absence of any effect of the time of day on the measure of bioelectric resistance. These results are presented in Table 23.

TABLE 23. Test for Diurnal Variation in the Cross-Sectional Resistance Data. Regression of Resistance Versus Time of Day by Sex.

Sex	Independent Variable	Regression Coefficient	t Statistics for HO:Coefficient =0	P Value
Men (N=82)	Intercept	493.80	17.15	< 0.001
	Time of Day	-3.16	-1.21	0.230
Women (N=82)	Intercept	611.33	14.84	< 0.001
	Time of Day	-3.57	-0.99	0.323

Summary

Analyses of both serial and cross-sectional data failed to demonstrate significant diurnal effects on bioelectric resistance measurements made during daytime hours (0900-1700). Thus, the bioelectric impedance method of measuring body composition may be used at any time of day, within the time range tested, without compromising its validity.

DIET AND EXERCISE EFFECTS

Hypothesis

The following hypothesis was used to test for the effects of exercise or diet on measures of bioelectric resistance:

> Predictions of body composition from stature^2/resistance and anthropometric data and/or the differences between these predictions and estimates from underwater weighing were not affected by diet and/or exercise.

Sample and Methods

<u>Sample</u>

This sample consisted of the 177 participants who each participated in measures of underwater weighing, anthropometry, residual volume, and bioelectric resistance. A complete description of this sample is presented on pages 22-23.

Methods

Questionnaire data were obtained from each participant in regard to their diet, salt usage, previous 24-hour food consumption, time of last drink and/or meal, and drug, smoking, and alcohol usage. Samples of these questionnaire forms are in Appendix A. The dietary questions focused on recent changes in the patterns of food consumption and the use of special diets. The 24-hour diet history noted the times, places, and kinds of foods consumed in the immediately preceding 24 hours. Also, each participant was asked about the kinds, amounts, and time at consumption of any over-the-counter or prescription medications, tobacco, caffeine, and alcohol. Questionnaire data were also obtained regarding the kinds, levels, frequency, and duration of any physical activity.

Results and Discussion

Results

In the preceding 24 hours, 56% of the sample had consumed one can of "cola," 68% had had at least one cup of coffee or tea, 85% had smoked at least one cigarette, and 72% had consumed some form of alcoholic beverage. As seen in Table 24, distribution statistics for the intervals from last drink and last meal show little difference between the sexes with means of about 6-7 hours for the intervals from the last meal and about 3 hours for the intervals from the last drink. At the minimum, the intervals from the last meal and from the last drink were about one hour for each sex, and at the maximum, the intervals were 19-23 hours for the last meal and 14-15 hours for the last drink.

Questionnaire data were obtained in regard to physical exercise. Exercise Group 1 (EG1) included 24 men and 34 women who reported that they did not participate in physical activity. Exercise Group 2 (EG2) was composed of 35 men and 23 women who had participated in physical activity in the preceding week but not during the 24-hour period preceding the examination. Exercise Group 3 (EG3) included 34 men and 27 women who had participated in physical activity during the 24 hours preceding the examination.

TABLE 24. Distribution Statistics for Interval from Last Meal and from Last Drink.

Variables	N	Mean	SD	Maximum Value
Men				
Last Meal (hours)	94	7.3	5.9	19
Last Drink (hours)	94	3.2	3.2	14
Women				
Last Meal (hours)	84	6.4	6.1	23
Last Drink (hours)	84	3.4	3.6	15

Because of the diversity and complexity of the recalled dietary data, it was not possible to categorize participants to test for possible dietary effects on measures of bioelectric resistance. Analyses of covariance were performed for men and for women separately for the physical exercise groups. The intervals from last drink and last meal to the time of the examination were treated as continuous variables. These analyses of covariance related to the differences between predictions of BD, %BF, TBF or FFM from "stature^2/resistance plus anthropometry" and from underwater weighing. In the men, neither the effects associated with exercise group membership nor those associated with interval from last drink or interval from last meal were significant. Thus, for the men, presence or absence of exercise or length of interval from last meal or last drink had no significant effect on differences in predictions of body composition from stature^2/resistance plus anthropometry and from underwater weighing. In addition, there were no significant additive effects of the intervals from last meal and those from last drink. Tables of the results of these analyses are found in Appendix E.

Corresponding analyses were made for the women. Exercise group membership had significant effects on the differences between predictions of either BD, %BF, TBF, or FFM from stature^2/resistance plus anthropometry and those from underwater weighing. Tables of these results are found in Appendix E, and these results are summarized in Table 25. These data were not adjusted for intervals from last meal or drink because the predicted values were not significantly associated with these intervals. The results that are summarized in Table 25 are based upon Duncan's Multiple Range Test.

TABLE 25. Mean Differences† Between Estimates of Body Composition from Stature^2/Resistance Plus Anthropometry and from Underwater Weighing for Exercise Groups in Women.

Body Composition Variable	Exercise Groups EG1	EG2	EG3
BD (gm/cm^3)	-0.003*	0.002	0.003
%BF (%)	1.456*	-0.865	-1.306
TBF (kg)	0.929*	-0.698	-0.706
FFM (kg	-0.929*	0.698	0.706

EG1. No exercise at all
EG2. Exercise but not in past 24 hours
EG3. Exercise in past 24 hours
*. Significant difference (P<0.05) between pairs of means, EG1 and EG2 and EG1 and EG3.
†. Calculated by subtracting the estimate from "stature^2/resistance plus anthropometry" from the estimate from underwater weighing.

In the group without exercise (EG1), estimates of BD or FFM from underwater weighing were less than corresponding predictions from stature^2/resistance plus anthropometry, producing negative mean differences that were statistically different from corresponding values in Exercise Groups 2 and 3 (Table 25). For %BF or TBF in Exercise Group 1, estimates from underwater weighing were larger than corresponding predictions from stature^2/resistance plus anthropometry, producing positive mean differences that were also statistically different from corresponding values in Exercise Groups 2 and 3 (Table 25). For the women without regular exercise (EG1), stature^2/resistance plus anthropometry overpredicted BD or FFM and underestimated %BF or TBF, compared to corresponding estimates from underwater weighing. For those women who had some form of regular exercise (EG2 and 3), there was no effect of the occurrence of exercise on differences in estimates of body composition from stature^2/resistance plus anthropometry and from underwater weighing. Thus, the absence of regular exercise appears to affect the difference between predictions of body composition from stature^2/resistance plus anthropometry and from underwater weighing in women.

Discussion

Body composition values were not associated with intervals from last meal or last drink in either sex despite considerable variation in the time of occurrence of these events. There were, however, significant differences between exercise groups in differences between predictions of body composition from stature^2/resistance plus anthropometry and from body density in the women. Compared to corresponding estimates from underwater weighing, stature^2/resistance plus anthropometry tended to underpredict %BF or TBF and overestimate BD or FFM in those women without regular exercise. The basis of the apparent effect of the absence of exercise on differences in predictions from resistance and from underwater weighing in the women is unclear. It is known that underwater weighing overpredicts the body fatness of athletes due to a greater density of FFM (142).

MENSTRUAL CYCLE VARIATION

Hypotheses

The following hypotheses were tested in relation to the variability in bioelectric resistance during the menstrual cycle:

1. There is no variation in serial measures of bioelectric resistance in women taking oral contraceptives or in women not taking oral contraceptives.

2. The interval from first day of last menstrual period has no effect on measures of bioelectric resistance.

Hypotheses 1 and 2 were tested serially first with a small pilot study and then with a much larger study of 29 women. Hypothesis 2 was tested using the cross-sectional data from the 85 women who were part of the validation study described on page 23-24.

Pilot Study

Sample. A pilot study was made using an independent sample of six white women. These women were not a subsample of any earlier samples. Three of these women were taking oral contraceptives and three were not taking oral contraceptives. The three women taking oral contraceptives were between

26.5 and 27.7 years of age, between 165 and 169 cm tall, and 55 to 90 kg in weight. The three women not taking oral contraceptives were between 35.5 and 46.8 years of age, between 164 and 168 cm tall, and 71 and 76 kg in weight.

Methods. Bioelectrical resistance measurements were recorded from the right side of each woman at approximately the same time of day for 35 consecutive days by one observer. The technique for measuring bioelectric resistance is the same as that described on page 16 and in Appendix B. At each daily visit, each woman was asked whether or not she was menstruating.

Time trend models were fitted to these data. These models are appropriate for determining a pattern across time. They can be fitted using regression analysis. A detailed discussion of time trend analysis is presented in Appendix F.

The serial data for stature^2/resistance were log transformed to stabilize the variance before analyses of variance were performed. These analyses were made for data recorded on paired days in successive cycles to determine whether the between-individual variance exceeded the within-individual variance.

Results and Discussion. The linear and quadratic trends in the stature^2/resistance data were not significant for any of the women. These findings showed that systematic trends were not present during the menstrual cycle. However, in two of the women not taking oral contraceptives, there were marked increases in stature^2/resistance 14 days after the onset of menstruation (Figure 3). This increase at about the time of ovulation could have been a random effect without biological significance. Nevertheless, the findings from this pilot study warranted obtaining serial data from a larger sample so that more definite conclusions could be reached regarding the relationship between bioelectric resistance and the menstrual cycle.

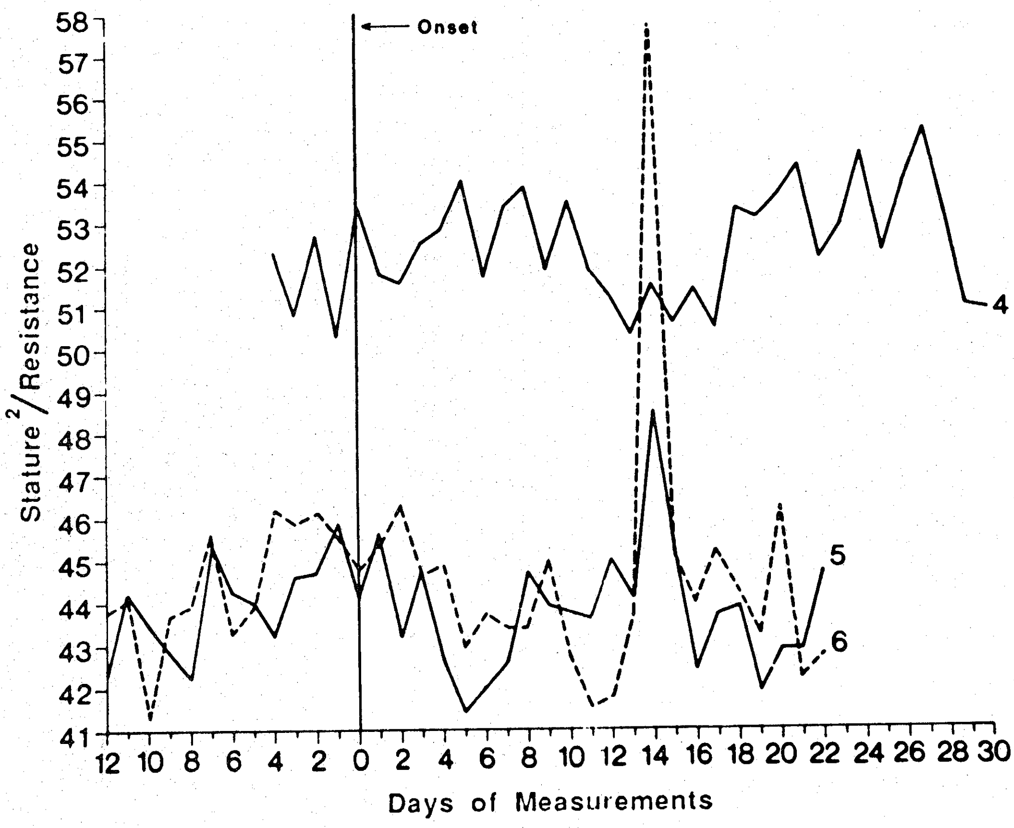

Figure 3. Serial measurements of stature^2/resistance in three women not taking oral contraceptives.

Sample and Methods

Sample

The study sample consisted of twenty-nine women who were not a subset of any of the other samples. Five of these women had participated in the pilot study described previously. Eleven of these women, aged 22 to 30 years, were taking oral contraceptives and eighteen, aged 21 to 38 years, were not taking oral contraceptives. Within this sample, there were two black women who were not taking oral contraceptives. The remaining 27 women were white. Each woman who agreed to participate stated she would be available for study at the same time each day for 35 consecutive days. Forms for informed consent and data collection are in Appendix A.

Methods

Each woman was requested to come for pre-testing one to two days in advance of the start of her 35-day measurement period. At this visit, weight, stature, and arm and calf circumferences were measured by each of two observers working independently. Descriptions of each anthropometric technique are presented in Appendix B. Each woman was assigned a mutually agreed upon time at which to return daily to be measured for the next 35 consecutive days. At each daily visit, weight was measured and two resistance measures were made from the right side of each woman when she was wearing a minimum of street clothing. Since the study occurred during May and June, the women wore light clothing. Three Bioelectrical Impedance Analyzers were used to record the bioelectric resistance values.

After each woman had completed her 35-day measurement period, she returned for a remeasurement of weight, stature, and arm and calf circumferences. The significance of the differences between oral contraceptive users and non-oral contraceptive users was tested for data at the first and at the final examinations. A 2-sided Mann-Whitney U-test was used because of the small sample size in each group and probable non-normality.

Distribution statistics were calculated, within women, for the serial stature^2/resistance and weight values, daily increments of these and first and last statures. Rank order correlations between the coefficients of variation for stature^2/resistance and for weights within women were calculated to determine whether the variability within women was significantly associated between stature^2/resistance and weight.

Daily values for %BF were estimated using the regression equation in Appendix C, Table C-6. The independent variables needed for application of this estimation equation were derived as follows:

Impedance -	The first of the resistance values recorded each day.
Weight (kg) -	The value recorded each day.
Stature Calf circumference (cm) Arm circumference (cm)	Means of the two values recorded on the first day and two values recorded on the last day.
Age (years) -	Calculated as age at 31 May 1985 which was approximately the commencement of data collection.

An analysis was made to determine the number of days on which resistance had to be measured to approximate the "true" value. The true value was considered to be the mean of the daily measurements. This analysis was based on correlations between the true value and the values on random single days, on the first days of the menstrual cycles, and means of the data recorded during the 4 days at the beginning of each cycle.

Results and Discussion

Results

There were no differences in the anthropometric variables between the first and last examination or between those women taking or not taking oral contraceptives. These results are found in Appendix G, Tables G-1 and G-2. In addition, the differences in the mean impedance values recorded with each machine were not significant (Bioelectrical Impedance Analyzers): 583 ohm (SD 64 ohm); 582 ohm (SD 68 ohm); 580 ohm (SD 66 ohm).

Oral Contraceptive Group. The mean values for stature^2/resistance, derived from 34 to 35 daily values for each woman, ranged from 38.56 to 58.79 cm^2/ohm. The standard deviations varied from 0.87 to 2.17 cm^2/ohm, and the ranges (minimum to maximum) varied from 3.69 to 11.89 cm^2/ohm within women (Table G-3). Distribution statistics were calculated for daily increments in stature^2/resistance for each woman (Table G-4). The mean (signed) increments were near zero, but the standard deviations were from 1.06 to 2.84 cm^2/ohm per day. The median increments varied from −0.44 to −0.49 cm^2/ohm per day, and the ranges (minimum to maximum) varied from 2.12 to 9.34 cm^2/ohm per day within women.

Decreases in stature /resistance occurred in six of the 11 women during intervals from four days before to four days after the commencement of menstruation. However, in four of the 11 women, there were increases in the values of stature^2/resistance from two days before to two days after the commencement of menstruation, and in a fifth woman there was a borderline decrease. The day of the minimum stature^2/resistance value and the day of the maximum stature^2/resistance value were identified in the serial data for each woman, but these days were distributed randomly through the cycles (Table G-5). Figure G-1 displays the serial stature^2/resistance data for women taking oral contraceptives. These plots allow visual recognition of the days with the minimum values.

The standard deviations in weight for each woman ranged from 0.35 to 1.20 kg, but the ranges were from 1.6 to 5.4 kg within women. The largest day-to-day changes varied from 0.8 to 2.1 kg/day; however, the mean daily increments of weight (kg/day) within these women were near zero. These results are in Tables G-6 and G-7. Rank order correlations between coefficients of variation for stature^2/resistance and for weight were not significant.

Daily predictions of %BF were made using the equation in Table C-6. The means for estimated %BF averaged for all days for each woman ranged from 20.79 to 49.75% with standard deviations of 0.67 to 1.63%. The ranges for each woman were from 3.09 (minimum) to 9.86% (maximum). The mean daily increments for each woman were close to zero with standard deviations that varied from 0.93 to 2.36%; the largest increments ranged from 1.61 to 7.34% (Tables G-8 and G-9).

The correlation between stature^2/resistance on a random day in each serial record and the means for all days was +0.89. The correlation between stature^2/resistance on the first days of the menstrual cycles and the means for all days was +0.98 which increased to +0.99 when the mean for the first four days of the cycle was correlated with the mean for all days.

Daily data for stature^2/resistance could be matched with stature^2/resistance data for some corresponding days in successive menstrual cycles. The differences for paired data were analyzed using analysis of variance. The values for stature^2/resistance were based on the means of two measures for stature on both the first and on the last day of each series of measurements. The bioelectric resistance values used were the first of the two values recorded each day. The between-individual variance was only slightly greater than the within-individual variance with P-value of 0.09.

Autocorrelations of the errors (residuals from regression) were calculated using the serial stature^2/resistance values for each woman. In nine of the women, a Durbin-Watson test for the first through the fifth order correlations was non-significant ($\alpha = 0.05$) indicating that the values on particular days were not significantly correlated with the values on any of the five days immediately following (Table G-10). Consequently, the intercepts and the regression coefficients for these women could be interpreted without adjustment. In each of these nine women, the intercept was positive and significantly different from zero, but the slope (cm^2/ohm per day) was small and in only two of the women were the slopes significantly different from zero. In two of the women there were significant autoregressions. In Participant No. 8, there was a significant third order autocorrelation of the residuals showing that the daily values for stature^2/resistance were positively associated with the corresponding values three days later. Also Participant No. 6 showed significant first and third order autocorrelations of the residuals for daily values of stature^2/resistance. The significant autocorrelations for this subject demonstrated that the daily values for stature^2/resistance were negatively correlated with the values one day later and positively correlated with the values three days later.

To determine whether the pattern of change for all days combined within each woman was rectilinear or curvilinear, regressions of stature^2/resistance against days and days^2 from the last menstrual period were calculated. "Days" refers to the time intervals between the first days of the last menstrual periods and the days of the examinations (Table G-11). The intercepts were significant at α = 0.05 in each woman, but the coefficient for days was significant in only two women, and the coefficient for days^2 was significant in only three women.

Non-Oral Contraceptive Group. Each participant was measured on 35 consecutive days, except for three women who were measured on 34 consecutive days. The means for the measurements within women varied from 30.84 to 64.82 cm^2/ohm with standard deviations that ranged from 0.95 to 2.78 cm^2/ohm. The ranges for each woman varied from 3.74 to 17.27 cm^2/ohm. The days with the maximum stature^2/resistance values were randomly distributed within the menstrual cycles (Tables G-12 and G-13, Figure G-2).

The means for daily increments in stature^2/resistance for each woman were close to zero and ranged from -0.11 to +0.08 cm^2/ohm per day with standard deviations that varied from 0.87 to 3.67 cm^2/ohm per day. The largest daily increments within women ranged from 2.21 to 14.21 cm^2/ohm per day (Table G-14).

The daily weights differed markedly among the women, with a variation from 50.21 to 117.97 kg, and the standard deviations ranged from 0.27 to 1.38 kg within the women. The ranges of daily weights for each woman varied from 1.0 to 5.8 kg. The mean daily increments were close to zero, and the standard deviations of the daily increments ranged from 0.30 to 0.76 kg/day (Table G-15). The largest increments ranged from 0.5 to 2.0 kg/day (Table G-16). Rank order correlations between the coefficients of variation for stature^2/resistance and for weight were not significant.

Estimates of %BF were made for each of the women using the estimation equation in Table C-6. The means of daily predictions for each woman varied from 17.64 to 63.75%, and the standard deviations for the daily predictions within each woman ranged from 0.75 to 2.23% (Table G-17). The ranges for each woman varied from 3.41 to 13.93%. The means within each woman were close to zero, but the standard deviations ranged from 0.88 to 1.93%. The increments within women ranged from 3.25 to 8.83% (Table G-18).

The correlation between the values of stature^2/resistance on one random day and the means of the values for all days was 0.97. The correlation between the value of stature^2/resistance on the first days of the menstrual cycles and the means of the values for all days was 0.98. The latter coefficient increased to 0.99 when the means of values for the first four days of the cycles were correlated with the means for all days.

Thirteen of the women had a series of daily measurements of stature^2/resistance that included corresponding days in successive menstrual cycles. An analysis of variance, applied to the data for pairs of corresponding days, showed that the between-individual variance did not differ significantly from the within-individual variance.

Autocorrelations between residuals were calculated using the daily values of stature^2/resistance for each woman. In 11 of the women, these autocorrelations were not significant ($\alpha = 0.05$). The intercepts were significantly different from zero in each of these women. The slopes (cm^2/ohm per day), which are referred to as the "days" term in Table G-19, were significantly different from zero ($\alpha = 0.05$) in two of the women; in one the value was positive and in the other it was negative. There were some significant autocorrelations in the other women. Adjustments were made for these prior to the regression analyses. Daily values for stature^2/resistance were regressed against days and against days^2. In 13 women without significant autocorrelations, the intercepts were significant ($\alpha = 0.05$), and the coefficients for days and days^2 were significant in five of these women (Tables G-19 and G-20).

After adjustments for the significant autocorrelations in five of the women, the intercepts were significant ($\alpha = 0.05$), but the coefficients for days and for days^2 were not significant, except for one woman whose coefficient for days had a significant negative value and for days^2 had a significant positive value.

<u>Cross-sectional Study</u>. Data were also analyzed using the cross-sectional bioelectric resistance and menstrual records from the larger sample of 85 women, described on pages 23-24. Seventy-five of these women had a history of regular menstrual periods (variation less than ± 4 days in cycle intervals), and 15 were oral contraceptive users. At the time of examination, 17 of the women were

menstruating. The mean interval between the first day of the last menstrual period and the date of examination was 11.13 days (SD 7.58 days) with a maximum interval of 32 days.

These 85 women were classified into two groups according to use or non-use of oral contraceptives. Using bioelectric resistance as the response variable and time interval from the first day of last menstrual cycle to the date of examination as a covariate, an analysis of covariance was performed to determine the effect of oral contraceptive use adjusting for days since the beginning of the menstrual cycle (Table 26). In the analysis, the assumption of linearity between the response variable and the covariate and the assumption of common slope between the groups in the relationship of response variable and covariate were justified.

The effect of oral contraceptives on bioelectric resistance was not significant when the data were adjusted for the interval from the first day of the last menstrual period to the examination. The interval from the last menstrual period was not associated significantly with the values for stature^2/ resistance in the oral and non-oral contraceptive groups combined.

TABLE 26. Analysis of Covariance, Testing the Main Effect of Oral Contraceptive Usage on Measures of Bioelectric Resistance with Interval Between First Day of the Last Menstrual Period and the Date of Examination as a Covariate.

Source of Variation	DF	Sum of Squares	F	P
Oral Contraceptive (α) (after mean and covariate)	1	$R(\alpha\|\mu,b)=1851.58$	0.49	0.484
Days from last menstrual period (b) (pooled within-class regression)	1	$R(b\|\mu,\alpha)=1454.72$	0.39	0.535
Residual	68	SSE=254387.80		
Days from last menstrual period (Ho: parallelism of the slopes)	1	$R(\alpha b\|\mu,\alpha,b)=3977.32$	1.06	0.31
Residual	67	SSE=250410.48		

Discussion

Analyses of the serial data were made separately for oral and non-oral contraceptive users because the data from the pilot study indicated possible differences in bioelectric resistance associated with oral contraceptive use. Since comparisons between the groups could be influenced by body size differences, the oral and non-oral contraceptive users were compared with regard to weight, stature, and arm and calf circumferences. The differences were not significant. The results of analyses of stature^2/resistance were generally similar for the oral contraceptive and for the non-oral contraceptive groups. In each group, the means of daily values for stature^2/resistance varied markedly between women, as did the standard deviations and the increments in stature^2/resistance.

In the pilot study, two women taking oral contraceptives had shown decreases in stature^2/resistance about the time of ovulation. These results were not confirmed in the larger study where increases and decreases occurred with about equal frequency at this time.

There was also interest in weight changes within the women because large systematic changes in weight could have been associated with changes in bioelectric resistance. In some women, there may be a marked weight gain and water retention in association with menstruation (143-147) and resistance values are closely associated with total body water and the concentrations of ions in body fluids (99, 104). There is considerable inter-individual variation in weight changes in relation to menstruation with a second weight peak 14 to 21 days after the onset of menstruation in some women (143). Others regard weight changes in relation to menstruation as random fluctuations rather than effects of physiological processes (145). The changes in weight and hydration are not large enough in normal women to affect measurements of body density from underwater weighing (148).

Daily weight fluctuations occurred in all the women, but in neither the oral contraceptive group nor in the non-oral contraceptive group did weight tend to change systematically in relation to the menstrual cycle. The findings for weight were similar to the daily changes reported in the literature for young women. After the effects of significant linear trends were removed, Robinson and Watson (144) found a mean adjusted daily change of 0.28 kg, with a range of 0.59 to 2.07 kg. Others have reported that standard deviations for daily weights ranged from 0.20 to 0.38 kg (147) and that the daily changes exceeded 0.5 kg on 13.4% of occasions and exceeded 1.0 kg on 1.8% of occasions (144). About 30 percent of women gain 1.3 kg or more in weight during the premenstrual or menstrual phase of the cycle (149). In the present study, the variability in weight was not significantly associated with the variability in stature^2/resistance.

The equation using stature^2/resistance and selected anthropometric variables as predictors of %BF (Table 19, page 46) was applied to the serial data for the women. There were marked differences in the predicted %BF values between the women within each group. The values tended to be higher in the non-oral contraceptive group to an extent that was just significant ($t=1.80$; $0.05<P<0.1$,), but serial trends were not significant in either group.

The use of bioelectric resistance in anthropometric surveys depends upon whether a measurement of resistance on a random day during the menstrual cycle is sufficiently representative of the true value for a woman. The true value, for this purpose, was assumed to be the mean of the values for 35 consecutive days. The results showed that a measurement on any one day was sufficiently accurate. An analysis of variance for stature^2/resistance on paired days within successive cycles showed that the between-individual variance was greater than the within-individual variance in the oral contraceptive group, but not in the non-oral contraceptive group. This reflected the relatively larger between-individual variance and the relatively smaller within-individual variance in the oral contraceptive group compared to the non-oral contraceptive group. It was concluded that measurements on a random day in each of two menstrual cycles were indicated for non-oral contraceptive users. This conclusion is tentative because of the small number of subjects. The results for the oral contraceptive group showed that the between-individual variance was greater than the within-individual variance. This implied that a random day in a single cycle would provide sufficient information. This conclusion is provisional because the P value was marginally significant ($P=0.09$).

Regressions of resistance versus days and $days^2$ from the previous menstrual period to the days of examination were calculated, after adjustments for significant autocorrelations. The intercepts were significant in all women, but the terms for days and for $days^2$ were significant no more commonly than would be expected due to chance. This showed that there were no linear or non-linear systematic trends in the resistance values in relation to timing within the menstrual cycle.

A total of 1184 pairs of serial bioelectric resistance measurements were made on 35 individuals combining data from the serial data and the cross-sectional data. Five of the daily resistance values for individuals are probably artifacts. These are all low values. Two occurred on the 14th days of the menstrual cycles (Nos. 5 and 6 in the pilot study), one on the 3rd day of the cycle in a woman not taking oral contraceptives (No. 3), one on the 8th day of the cycle in a woman (No. 32) not taking oral contraceptives, and one on the 8th day of the cycle in a woman who was taking oral contraceptives (No. 9). The cause of these probable artifacts is obscure. Daily measurements of the test object (calibration) showed almost no variation. Defects in the conduction system between the impedance analyzer and the women (loose contacts, microfractures, etc.) are likely to cause irregular (unstable) values rather than low ones (150).

SUMMARY

It is concluded on the basis of these serial and cross-sectional studies that when bioelectric resistance values are used to predict the body composition of women, there is no need to record data relating to oral contraceptive use and that it is not necessary to control the timing of resistance measurements in relation to the menstrual cycle.

VALIDITY OF ULTRASONIC DATA

RATIONALE

Ultrasonic measurements of subcutaneous adipose tissue thickness are not affected by inter-individual differences in tissue compressibility as are skinfold caliper measurements (94). Also, ultrasonic measurements of subcutaneous adipose tissue can be taken at body locations where skinfold calipers cannot be used, such as the breast and buttocks, and in the obese, where a skinfold thickness may be too large to be measured. Ultrasound has not been commonly used to measure subcutaneous adipose tissue thickness because available instruments were not portable and had poor accuracy and validity.

The EchoScan 1502 ultrasound equipment is light in weight (3.6 kg), portable, non-invasive, safe for human use, and is applicable to all ages, sexes and racial groups present in the U.S. Army. Preliminary data indicated that this instrument can provide local estimates of subcutaneous adipose tissue thicknesses. To be of value, however, ultrasonic measurements must be accurate, reliable, and provide valid estimates of subcutaneous adipose tissue thickness, TBF and %BF. Consequently, testing must involve comparisons with skinfold thicknesses and with estimates of TBF and %BF from densitometry.

The EchoScan 1502 can measure adipose tissue thickness with a resolution of $\pm$ 0.1 mm. For acceptance of the EchoScan instrument, it must provide accurate estimates of subcutaneous adipose tissue thickness that as good if not better than skinfold caliper measurements of subcutaneous adipose tissue thickness as predictors of TBF or %BF. Also, it is important to determine whether or not ultrasonic measurements are affected by other body dimensions or physiological factors.

VALIDATION

Hypotheses

The following hypotheses were tested to determine the accuracy, validity and independence of ultrasonic measures of subcutaneous adipose tissue thickness:

1. Ultrasonic measures of subcutaneous adipose tissue thickness with an EchoScan 1502 are accurate in comparison to corresponding Lange skinfold caliper measurements.

2. Ultrasonic measures of subcutaneous adipose tissue with an EchoScan 1502 will not improve estimates of body density from skinfold caliper measurements and stature^2/resistance.

Sample and Methods

Sample

The sample consisted of the 177 men and women who each participated in measures of underwater weighing, anthropometry, residual volume, bioelectric resistance, and ultrasonic measures of subcutaneous adipose tissue thickness (pages 23-24). Data collection recording forms are in Appendix A.

Methods

Ultrasonic measures of subcutaneous adipose tissue thickness were made with an EchoScan 1502 portable machine at the same body locations as the skinfold measurements and at additional sites over the breast and buttocks. Skinfold measurements of subcutaneous adipose tissue thickness were made with Lange skinfold calipers. The ultrasonic and skinfold caliper measurements were each recorded twice by each of two independent observers. The following ultrasonic and caliper measurements were taken with the participant standing: triceps, biceps, subscapular, and midaxillary. The remaining measurements were taken with the participant supine: breast (ultrasound only), paraumbilical, anterior thigh, and lateral calf. The ultrasonic measurement of the buttocks was taken with the participant prone. Bioelectric resistance was also recorded from each participant as described on page 16. All measurements were taken from the right side of the body on the same day. Complete descriptions of the anthropometric bioelectric resistance and ultrasonic measurement are in Appendix B.

Results and Discussion

Results

Hypothesis 1

Correlations were calculated between observed values and between squares of observed values for EchoScan and Lange caliper measurements for men and women separately. The results are presented in Table 27. All the correlation coefficients were significant. It was considered desirable to correlate amongst squares of the observed values because squares may be used in equations to calculate indices of adipose tissue areas or of muscle/adipose tissue areas for the upper arm or the calf. The coefficients for the observed values were higher in the men than in the women for six of the seven sites. The highest coefficients for the observed values were for the anterior thigh site in the men and for the subscapular site in the women.

When the correlations were based on squares of the observed values, the highest coefficients were those for the midaxillary and paraumbilical sites while the lowest coefficients were those for the biceps site in each sex. The correlations based on the squares of observed values were similar to those based on the observed values except for measurements at the midaxillary, paraumbilical, and lateral calf sites for which, in each sex, the correlations based on squares were markedly larger.

The caliper measurements were regressed on the ultrasonic measurements at each of the seven sites within sex. These results are presented in Appendix H. The intercepts had positive values ranging from 3.84 to 5.87 mm. They were not significantly different from zero (t-test; $P < 0.05$) except those for the subscapular site in the men and for the paraumbilical, triceps, and lateral calf sites in the women. The slopes had values ranging from 1.33 to 2.55. The values for the slopes tended to be larger in the men than in the women, and they were all significantly different from unity (one-sided t-test; $P < 0.05$) except for the subscapular site in the men.

The correspondence between skinfold and ultrasonic measurements was also examined by constructing a series of contingency tables. The data recorded at matching sites with two techniques within the same participants cannot be assumed to be independent. Therefore, chi-square tests were not applicable. However, these tables allow some non-statistical judgments. Agreement between methods in quartile assignment was better at the higher quartiles and tended to be better for men than for women. These results are tabulated in Appendix H.

TABLE 27. Correlations Between Corresponding Ultrasonic and Lange Skinfold Caliper Measurements of Subcutaneous Adipose Tissue Thickness in Men and Women.

	Men		Women	
	n	r**	n	r**
Observed Values				
Triceps	85	0.73	82	0.62
Biceps	85	0.45	81	0.55
Subscapular	85	0.75	82	0.68
Midaxillary	85	0.75	81	0.59
Paraumbilical	84	0.57	81	0.41
Anterior Thigh	83	0.81	70	0.64
Lateral Calf	83	0.72	73	0.56
Squared Values				
Triceps	85	0.72	82	0.60
Biceps	85	0.47	81	0.52
Subscapular	85	0.76	82	0.62
Midaxillary	85	0.89	81	0.80
Paraumbilical	84	0.82	81	0.79
Snterior Thigh	83	0.81	70	0.62
Lateral Calf	83	0.80	73	0.66

**P < 0.01 (all tests)

Hypothesis 2

The utility of ultrasonic data was examined by comparing the effectiveness of four models for the prediction of BD (Model I = skinfold thicknesses; Model II = Model I plus ultrasonic variables significantly correlated with BD after adjusting for the skinfold thicknesses; Model III = Model I plus stature^2/resistance; and Model IV = Model II plus stature^2/resistance). The RMSE for men were not significantly altered by the addition of the ultrasonic data or stature^2/resistance to skinfold thickness (Table 28). Similar results were obtained for women.

The root mean square errors (RMSE) from these regression equations were all larger in the women than in the men. This reflects, at least in part, the larger mean values in the women. The RMSE tended to be larger for the paraumbilical site and small for the biceps and lateral calf sites in each sex. These differences between sites in RMSE are probably also related to the mean values.

TABLE 28. Prediction of Body Density from Underwater Weighing in Men by Maximum R^2 Equations.

	Model I[a]	Model II[b]	Model III[c]	Model IV[d]
R^2	0.67	0.72	0.68	0.74
Adjusted R^2	0.66	0.71	0.66	0.72
RMSE	0.0083	0.0077	0.0083	0.0076

a. Model I was built using skinfold thicknesses at seven sites as possible regressors.
b. Model II was formulated using Model I plus ultrasonic measurements at the sites where they were significantly (α=0.05) correlated with BD after adjusting for the skinfold thicknesses.
c. Model III was formulated using Model I plus stature^2/resistance.
d. Model IV was formulated using Model II plus stature^2/resistance.

Discussion

The present study has shown statistically significant correlations between pairs of caliper and ultrasonic values with r values ranging from +0.45 to +.85. These correlations are similar in magnitude to those reported by Borkan et al. (82). Regression analyses showed most of the intercepts did not differ significantly from zero, but most of the slopes were significantly greater than unity. This is not surprising because skinfold values exceed the corresponding ultrasonic values particularly at larger thicknesses. When ultrasonic data were added to models to predict BD from skinfold thicknesses, or from skinfold thicknesses plus stature^2/resistance, there were only small and non-significant changes in the adjusted R^2 values and in the RMSE. Given this finding, and considering the Echoscan's low reliability and high observer error rates, it was concluded that ultrasonic measurements of subcutaneous adipose tissue thicknesses with the EchoScan equipment were less satisfactory than skinfold measurements whether there is interest in total or regional body fatness.

EFFECTS OF PHYSIOLOGICAL FACTORS ON ULTRASONIC MEASUREMENTS

Hypothesis

The following hypothesis was used to test for the possibility of physiological factors on ultrasonic measurements:

> The difference between corresponding EchoScan ultrasonic measurements and Lange skinfold caliper measurements are not influenced by stature, weight, upper arm circumference, calf circumference, time of day, interval from last meal or drink, oral contraceptives, interval from last menstrual period, or recent exercise.

Sample and Methods

Sample

This sample also consisted of the 177 men and women who each participated in measures of underwater weighing, anthropometry, residual volume, bioelectric impedance, and ultrasonic measures of subcutaneous adipose tissue described earlier on pages 24-25.

Methods

Ultrasonic measures of subcutaneous adipose tissue thickness were made with an EchoScan 1502 portable machine at the same body locations as the skinfold measurements plus from the breast and buttocks. The location of these sites and the anthropometric and ultrasonic measurement techniques are described on page 25 and in Appendix B. The physiological data were the same as those collected for this sample as described on pages 53 and 58 and in Appendix B. Briefly, these data were related to diet, exercise, interval from last meal or drink, drug usage, and menstruation.

Results and Discussion

Results

A multiple regression model was applied to the data for each sex separately. This procedure allowed estimates of the effects of the factors considered on the differences between matching pairs of ultrasonic and caliper measurements of subcutaneous adipose tissue thicknesses (EchoScan less Lange calipers). There were significant negative associations between stature and differences between pairs of triceps, subscapular, midaxillary, and paraumbilical subcutaneous adipose tissue measurements in the men. Weight had significant positive associations with the differences between EchoScan and caliper measurements at the triceps, subscapular, biceps, midaxillary, and paraumbilical sites in the men. Arm circumference had a significant negative association with the differences between the pairs of paraumbilical subcutaneous adipose tissue measurements in the men. Also, calf circumference was negatively associated with the differences for the subscapular and paraumbilical sites, but was positively associated with the differences between pairs of subcutaneous adipose tissue measurements at the anterior thigh and lateral calf sites in the men. Only the significant results of this analysis are presented in Table 29.

TABLE 29. Significant Results* of Multiple Regression Analysis of the Differences Between Corresponding EchoScan Ultrasonic Measurements and Caliper Measurements of Subcutaneous Adipose Tissue Thicknesses (EchoScan Less Calipers) Versus Anthropometric Variables and Other Exogenous Factors in Men.

Variables	Triceps	Sub-scapular	Biceps	Mid-axillary	Para-umbilical	Anterior Thigh	Lateral Calf
Stature	-0.18	-0.29	...	-0.20	-0.52	...	...
Weight	0.23	0.44	0.05	0.26	1.20	...	...
Arm Circ.	...	...	...	...	-1.28	...	...
Calf Circ.	...	-0.60	...	...	-1.33	0.70	0.49
Time of day	...	...	...	...	...	...	...
Interval from Last Meal	...	...	...	...	...	...	...
Interval from Last Drink	...	...	...	...	...	...	...
Exercise Group	...	...	...	...	...	...	...

*. two sided t-test for regression coefficient equal to zero was significant at $\alpha = 0.05$ for each item with an entered value and excluding all non-significant values.

Data for the women showed that stature was significantly and negatively associated with the differences for the subscapular, biceps, and midaxillary measurements of subcutaneous adipose tissue (Table 30). Weight was significantly positively associated with the differences for the triceps, subscapular, biceps, and paraumbilical subcutaneous adipose tissue measurements. Arm circumference was positively associated with the differences between subcutaneous adipose tissue measurements at the biceps site only in the women. Calf circumference was significantly but negatively associated with the corresponding differences at the subscapular and biceps sites in the women, but was positively associated with the differences at the anterior thigh and lateral calf sites. Also, in the women, time of day was significantly associated with the differences between ultrasonic and caliper measurements of subcutaneous adipose tissue thickness at the subscapular and midaxillary sites. The interval from the last drink was positively associated with the differences at the biceps site, while the interval from the last menstrual period was positively associated with the differences at the midaxillary site.

Exercise level (see page 58 for categories) was treated in the analysis as a continuous variable with low values indicative of less physical exercise. The effects of exercise on the differences between caliper and ultrasonic measurements were not significant in the men, but in the women there was a negative association between exercise and the differences at the triceps site.

Discussion

These results indicate that the primary effect of the physiological factors on differences between ultrasonic and caliper measurements of subcutaneous adipose tissue relates to the compression of the caliper measurements. Theoretically, without compression, the value of an ultrasonic measurement should be equal to half the value of the caliper measurement of subcutaneous adipose tissue thickness. Since these are computed as ultrasonic measurement less caliper measurement, the larger the positive value from this subtraction, the greater the effect of compression on the skinfold caliper measurement. In the men and women, the negative associations with stature and the positive associations with weight indicate greater amounts of compression for the skinfold caliper measurements in shorter, heavier individuals. These results, plus the positive associations between limb circumferences and corresponding skinfolds and level of exercise, indicated that compression significantly affected skinfold caliper measurements compared to ultrasonic measures of subcutaneous adipose tissue thickness in the heavier individual. Since these effects were detectable in this sample, where few participants were obese, then one can expect similar, if not greater effects in a sample with a distribution of weights more representative of the U.S. civilian population.

TABLE 30. Significant Results* of Multiple Regression Analysis of the Differences Between Corresponding EchoScan Ultrasonic Measurements and Caliper Measurements of Subcutaneous Adipose Tissue Thicknesses (EchoScan Less Calipers) Versus Anthropometric Variables and Other Exogenous Factors in Women.

Variables	Triceps	Sub-scapular	Biceps	Mid-axillary	Para-umbilical	Anterior Thigh	Lateral Calf
Stature	...	-0.45	-0.17	-0.05	...	...	...
Weight	0.31	0.76	0.25	...	0.54	...	...
Arm Circ.	...	...	0.58	...	...	...	...
Calf Circ.	...	-0.77	-0.46	...	...	1.44	0.49
Time of day	...	0.64	...	0.89	...	...	...
Interval from Last Meal	...	...	...	...	...	...	...
Interval from Last Drink	...	...	0.10	...	...	...	...
Oral Contraceptive	...	...		...	...	...	...
Interval from Last Menstrual Period	...	...	...	...	0.09	...	...
Exercise Group	-1.43*	...	...	...	...	...	...

*. two sided t-test for regression coefficient equal to zero with the result being significant at $\alpha = 0.05$ for each item with an entered value and excluding all non-significant values.

SUMMARY

Ultrasonic measures of subcutaneous adipose tissue thickness with an EchoScan 1502 ultrasound machine are significantly correlated with corresponding measures from Lange skinfold calipers. In general, these correlation coefficients are similar to those reported for Lange or Holtain skinfold calipers and an Ithaco Body Composition Meter (85, 118). However, the correlation coefficients were less than corresponding coefficients where the ultrasound machine used was a sophisticated real-time scanner (121).

The findings of Fanilli & Kuczmarski (121) indicated that Lange skinfold calipers measures of subcutaneous adipose tissue thickness had larger correlation coefficients with body density than corresponding real time ultrasonic measurements. Borkan and co-workers (85) also reported similar results for prediction of body density from ultrasonic subcutaneous adipose tissue measurements with an Ithaco Body Composition Meter. Ultrasonic measures of subcutaneous adipose tissue can be used to group individuals into quartiles of fatness that agree with corresponding quartiles from skinfold caliper measurements. However, these groupings between methods have a greater degree of correspondence at the upper and lower quartiles. The distinct advantage of ultrasonic measurements is seen in the absence of the effects of compression that plague skinfold caliper measurements, particularly for large skinfold thicknesses.

CONCLUSIONS

FINDINGS ON RELIABILITY AND VALIDITY

This discussion focuses upon the testing that has been performed with the Bioelectric Impedance Analyzer Model BIA-101 and the EchoScan 1502 ultrasound machine.

The measurement of bioelectric impedance in the human body has great appeal as an index of body composition because the procedure is quick, noninvasive, and requires little observer training. The present study has shown that intra-machine differences are extremely small compared with the observed mean values. In fact, intra-machine reliability was excellent, with reliability estimates of 99.5% or more for each of two observers. An analysis of variance did not show significant main effects of machine or a significant machine x observer interaction. The intra-observer differences for the impedance measurements were small in men and women with a reliability of 98%. Inter-observer differences were equally small, and the reliability was about 99%. These excellent reliability results for the bioelectric impedance equipment are in agreement with those reported by others from generally smaller samples and with less complete sets of machine and observer differences (99,110-113,124).

Having demonstrated the reliability of impedance measurements, the question of validity was addressed. As a first step, it was shown that bioelectric resistance had significant negative correlations with weight, arm circumference, and calf circumference. Each of these anthropometric variables was also negatively correlated with BD, and positively correlated with %BF and TBF as has been reported by others (9,18,127,134,135). In the present data, the correlations between resistance and selected anthropometric variables remained significantly negative within sex-specific groups subdivided by race. Tests of the validity of impedance were also made by relating combinations of stature^2/resistance plus anthropometric variables to BD, %BF, TBF, and FFM from underwater weighing. The best equations for men were those including stature^2/resistance, weight, and calf circumference. The analyses for women showed the best equations included stature^2/resistance, weight, calf circumference, arm circumference, and age. The RMSE values for predicted body composition values were similar to those when the best combinations of stature^2/resistance and skinfolds were used.

Comparisons were made between black and white participants in regard to differences between body composition from stature^2/resistance plus anthropometry and those derived from underwater weighing. There were few black participants for statistical tests of significance especially for women, but the present data showed that predictions of body composition variables from stature^2/resistance plus anthropometry for black men would have to be altered to make the means equivalent to those derived from underwater weighing. The results of analyses suggested separate regression equations for black and for whites are desirable. It is expected that the RMSE for these equations would be smaller than those for the present equations.

The present validity tests can be compared with the SEE of 5.08% and 3.06% reported for a group of somewhat obese adults, aged 17-59 years, when stature^2/resistance was used to estimate %BF (68). The larger value was obtained when the equation of the manufacturer of the Bioelectric Impedance Analyzer was applied and the smaller was obtained with a study-specific equation using stature^2/resistance as the independent variable. A value of 6.04% for the SEE of %BF in lean young men, using stature^2/resistance, and the regression formula provided by the manufacturer has been reported (124). Others (113) have reported a SEE for FFM of 4.43 kg when stature^2/resistance was used to predict FFM employing the equation supplied by the manufacturer. When an equation developed in the same study (113) was used, in combination with weight, the SEE for FFM was 3.06 kg. Lukaski et al. (99) reported a value of 2.61 kg for the SEE of fat-free weight using their own regression equation that employed stature^2/resistance as the independent variable. When this equation was applied to a different sample, a SEE for TBF of 3.06 kg was obtained (124). In each of these studies, the "direct" measures of body composition were obtained from underwater weighing except that of Lukaski et al. (99) who employed TBW from D_2O.

This approach to the validation of bioelectric impedance as an index of body composition is based on the assumptions that BD can be measured without error by underwater weighing and that Siri's equation (20) accurately estimates %BF from BD, regardless of age or sex, after which TBF or FFM can be calculated. The accuracy of BD estimation depends almost entirely on the measurement of underwater weight and of RV. There is convincing evidence that underwater weighing is highly reliable (20,21,28-30,32-36,128,136). This was also the case in the present study where the inter-observer differences were small and reliability was high. RV measurements are also highly reliable (137). In the present study, the mean inter-observer differences were 0.1 L (SD 0.1 L within each sex) and the reliability was 97.8% or greater.

If the measurement of BD were completely free of error, the estimation of %BF from BD would have an error of about $\pm$ 2.5% because the equations used are far from ideal (13). Siri's equation (20), to estimate %BF from BD, yields results similar to those from the equation of Brozek et al. (21), except at low BD values (implying high values for %BF) when the estimates from the Siri equation are higher than those from the Brozek equation (13). These equations are appropriate for healthy young white men (138), but they are inappropriate for groups in which the FFM is more dense than the value assumed by Siri (20). This occurs in black men and leads to an underestimation of %BF (22). An opposite tendency (less dense FFM; overestimation of %BF) occurs in women (139) which has led to the development of a new equation for women (23,139).

In summary, estimates of %BF from underwater weighing have an SEE of about 2.5% (13). When values from underwater weighing are used as criteria, 2.5% becomes the irreducible minimum for the errors of estimation. Consequently, the finding, that the RMSE of the estimation of %BF from stature^2/resistance plus simple anthropometry is 4.002% for men and 3.893% for women, is a good result. The general conclusion from the present study is that stature^2/resistance plus anthropometry can provide more accurate predictions of body composition than anthropometry alone, and this finding is supported by published reports (10,68, 140,141).

The accuracy of the prediction of body composition from stature^2/ resistance plus anthropometry might have been affected by various physiological noise factors. However, diurnal effects were demonstrated to be nonsignificant.

Differences between predictions of BD, %BF, TBF, or FFM from stature^2/ resistance plus anthropometry, and from underwater weighing were not associated with the intervals from the last meal or last drink in either sex. The lack of significance in the present findings occurred despite considerable variance in the intervals with maximum intervals of 23.5 hours from the last meal and 15.0 hours from the last drink. There were, however, significant associations with exercise group membership in the women but not in the men. In women not taking regular exercise, stature^2/resistance plus anthropometry under-predicted %BF and TBF in comparison with underwater weighing. The basis for the apparent sex-associated difference in effects of exercise on the predictions from resistance and from underwater weighing is unclear. Siri's equation (20) produces large estimates of %BF at smaller values of density; thus, the significant effects are possibly due to the inherent error of applying Siri's equation to a group for which it is not appropriate. The apparent effect of the absence of exercise on estimates of body composition from bioelectric resistance in women may be an artifact of the use of Siri's equation.

Serial data in relation to the menstrual cycle for women taking oral contraceptives showed cyclic changes in stature^2/resistance that reflected changes in bioelectric resistance possibly in association with decreases in estrogens and progesterones coinciding with the monthly cessation of the use of oral contraceptives. Decreases in estrogens may be associated with decreases in total body water and sodium (149), but decreases in progesterone would be associated with increases in total body water and sodium (151-155). The present data suggests an estrogen effect, perhaps because the progesterone effect is reduced or completely inhibited by increases in aldosterones during this part of the cycle (153, 156-159). Studies in metabolic wards have also shown slight increases in weight, total body water, and sodium at midcycle when intakes of water, sodium, and potassium are fixed (160,161), and there is supporting evidence for these changes from other studies (162-165). Changes in body weight, TBW, and in sodium at midcycle are generally small, and, in the present study, there was little or no change in bioelectric resistance from one day to the next. These findings indicate that stature^2/resistance values were not related significantly to the timing of the present menstrual cycle or to one interval from the last menstrual period.

The ultrasonic measurement of subcutaneous adipose tissue has considerable appeal in regard to the regional measurement of body fatness. Some regional distributions (fat patterning) are associated with diseases or risk factors for diseases (73,166,167). Portable equipment is available (Ithaco, EchoScan) and its use would avoid the errors caused by individual differences in the compressibility of subcutaneous adipose tissue (84). Earlier studies of the Ithaco equipment have shown that it is not useful, because it has an accuracy of only 2.0 mm, and it is not reliable (82,168). The EchoScan machine has an accuracy of 0.1 mm, and it is easily portable. However, in the present intra-observer data, the caliper measurements (skinfolds) were more reliable than the ultrasonic measurements. There were also large differences in reliability in the inter-observer data. The reliability of skinfold thicknesses from the present study is generally higher than that reported by others (127-133). This may reflect the long-term experience and care of those making the skinfold measurements in the present study. The present observers also had experience with the Ithaco ultrasound equipment and took great pains to obtain the best possible data with the EchoScan equipment.

The present study indicated significant correlations between pairs of caliper and ultrasonic values. These correlations are similar in magnitude to those reported by Borkan et al. (82). However, when ultrasonic data were added to models to estimate BD from skinfold thicknesses or from skinfold thicknesses plus stature^2/resistance, there were only small and non-significant changes in the adjusted R^2 values and in the RMSE.

RECOMMENDATIONS

EchoScan 1502

The EchoScan ultrasonic machine is not recommended in place of skinfold calipers for the measurement of subcutaneous adipose tissue thickness. The main reasons are as follows:

> Ultrasonic measurements with the EchoScan machine are not as reliable as skinfold measurements, and they do not contribute significantly to the estimation of total body composition (BD, %BF, TBF, FFM) if skinfold thicknesses are available.
>
> This equipment is expensive and two observers are needed when it is used.
>
> More intensive training is required to collect ultrasonic measurements than to make caliper measurements. The need for intensive training is indicated by the significant observer x machine interaction that could lead to multiplicative errors.

Ultrasound is still useful for the study of subcutaneous adipose tissue thicknesses if B mode equipment is used, but this equipment is not portable, and its use requires considerable training.

BIA-101 Impedance Analyzer

The Bioelectric Impedance Analyzer Model BIA-101 is recommended for use in future anthropometric surveys of U.S. Army personnel and in screening individuals in regard to body composition variables. The results for individuals should be reported with their confidence limits. The main reasons for this recommendation are as follows:

> Bioelectric resistance measurements made with the Bioelectric Impedance Analyzer are highly reliable.

Validation against BD indicates that predictive errors from the equations developed in this study are only slightly larger than those inherent to densitometry.

The Bioelectric Impedance Analyzer is portable, needs only one observer to operate it, requires minimal training of that observer, and takes only a few minutes of the subject's time.

The results of this study also support the following conclusions relative to the Bioelectric Impedance Analyzer:

There is no need to limit the time of day (within the range 0900 to 1700 hours) at which resistance is measured nor on the intervals from last meal (up to 23.5 hours) or from last drink (up to 15 hours) to the time of the measurement.

Women can have bioelectric resistance measured on any day whether they are menstruating or not, and whether or not they are taking oral contraceptives. A resistance measurement need be made on one day only.

The prediction equations from the present study should be applied instead of those supplied by the BIA manufacturer, until better equations are available. Sex-specific prediction equations are needed. In young adult men, weight and calf circumference should be used in combination with stature^2/ resistance. In young adult women, arm circumference and age should also be used. The combination of these anthropometric variables with stature^2/ resistance is recommended in preference to skinfolds with stature^2/ resistance. Observer errors are large when skinfolds are measured by inexperienced observers, whereas the accurate measurement of stature, weight, calf circumference and arm circumference requires very little training.

Strictly speaking, all prediction equations are applicable only to the populations from which they were derived. In particular, application of the equations from the present study to older individuals, those who are more extreme in fatness than the study sample, Mexican-Americans, or pregnant women, will lead to larger errors than those found in the present study. The development of prediction equations for other population groups, including women grouped according to their participation in strenuous activity, and the cross-validation of estimation equations is desirable. These prediction equations cannot be more accurate than direct measures of body composition from underwater weighing. The errors of body composition values from underwater weighing are acceptable for young adult white men, but are probably large for all other groups. These errors may be reduced when a series of equations to estimate body composition from body density for age- and sex-specific groups becomes available about June, 1986 (169). The collection of data for the development of equations to predict body composition from bioelectric impedance plus anthropometry could precede the development of age- and sex-specific equations to estimate body composition from body density.

The need for race-specific prediction equations is shown by the variations between blacks and whites in the differences between body composition predictions from stature^2/resistance plus anthropometry and those from underwater weighing.

All measurements should be made on the right side of the body because this side is measured in most U.S. Army anthropometric surveys. When there is reason to suspect marked asymmetry, both sides should be measured and the means of paired values used. There were no significant lateral differences in impedance values in the present study.

The following details should also be noted to assure maximal data validity when using the BIA-101 Analyzer:

Subject positioning for impedance measurements should be in accordance with the manufacturer's instructions taking care that the thighs are separated.

A test object should be measured at the beginning and the end of each data collection day. This is to ensure that the alligator clips and leads make good contact, that the leads do not have fractures, and that the battery is fully charged.

The importance of calibration should be emphasized. Each instrument should be provided with a spare set of cables. In cross-sectional surveys, it will be difficult to recognize inaccurate impedance data unless it is associated with unstable values. One potential safeguard is to measure with two instruments, each with its own set of cables, thus reducing within-machine effects.

The present recommendations refer to a specific instrument produced by a particular manufacturer. If alterations were made in this equipment by the manufacturer or by others, these recommendations may need to be changed and the accuracy of the prediction equations in this report may be affected.

These recommendations are made despite the fact that bioelectric impedance has a "black box" image because the method and the conductor are ill-defined. Stature^2, weight, calf circumference, and arm circumference provide only an index of the volume of the conductor. It is known that FFM and adipose tissue differ in their resistance to the passage of low frequency alternating currents (71,170), but the path traversed by the current during the measurement of resistance is unknown. It is assumed that FFM is favored and that the amount of extracellular fluid and its ionic concentration influence resistance values. Studies of extracellular fluid and serum in combination with bioelectric impedance are indicated.

SUGGESTED FURTHER RESEARCH

Suggestions for further research are restricted to the measurement and application of total body resistance.

Basic Research

-- Quantitative determination of the conductor pathway through the body.

-- Associations between resistance and extracellular fluid.

-- Possible measurement of extracellular fluid and intracellular fluid separately by varying the current.

Applied Research

-- There is convincing evidence in the literature that day-to-day changes in weight are larger for men than for women (138-139,144,147,171-175). Consequently, more variability in stature^2/resistance is likely within men than within women. A study of men and women with a wide range of values for physical activity and intervals from last food and last drink is recommended. The measurements should include resistance and underwater weight. A cross-over design with control of the variables of interest would be appropriate.

-- Development of equations for predicting body composition from body density in various sub-groups (age, ethnicity, sex, fitness, physical activity).

-- Development of equations for predicting body composition from resistance and anthropometry in various demographic sub-groups.

-- Cross-validation of new prediction equations with special emphasis on the frequency of quartile misclassification.

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ABBREVIATIONS

BIA = Bioelectrical Impedance Analyzer

BD = body density (gm/cm^3)

BF = body fat

CV = coefficient of variation

C(p) = Mallows' C(p) - see Appendix F

CR = coefficient of reliability

d = Durbin-Watson statistic

D = Komolgorov-Smirnov statistic

df = degrees of freedom

FFM = fat free mass (kg)

K = potassium

LBM = lean body mass (kg)

N = sample size

P = probability

R = multiple correlation coefficient

r = simple correlation coefficient

RMSE = root mean square error

RV = residual lung volume (L)

S = stature (cm)

SD = standard deviation

SE = standard error

SEE = standard error of the estimate

TBF = total body fat

TBW = total body water (L)

TE = technical error of measurement

TOBEC = total body electrical conductivity

VIF = variance inflation factor

Z = impedance (ohms)

APPENDICES

A. FORMS FOR INFORMED CONSENT AND FOR DATA RECORDING

B. ANTHROPOMETRIC, ULTRASONIC, AND BIOELECTRIC IMPEDANCE MEASUREMENT TECHNIQUES

C. EQUATIONS FOR PREDICTING BODY COMPOSITION IN MEN AND WOMEN FROM ANTHROPOMETRY AND STATURE^2/RESISTANCE

D. DISTRIBUTION STATISTICS

E. EFFECTS OF PHYSIOLOGICAL FACTORS

F. STATISTICAL METHODS

G. VARIATION WITH MENSTRUAL CYCLE

H. COMPARISON OF EchoScan 1502 AND LANGE SKINFOLD CALIPER MEASUREMENTS

APPENDIX A.

Informed Consent
U.S. Army Body Composition
Division of Human Biology

Please read all of this statement before signing or initialling any of the spaces provided. Your consent does not obligate you to participate, but is a simple statement of your intention to participate. Please initial the procedures to which you are willing to give your consent.

Description of Procedures

Our purpose in this research is to determine the most accurate methods for measuring fat in the human body. Valid measures of the human body are needed so that accurate assessments of nutritional status can be made.

In order to measure your body, you may be asked to wear a minimal amount of clothing; for example, shorts for men and a paper gown for women. These measurements will be made in a private place. All changing of clothes will be in private.

Anthropometry

You will be asked to allow certain measurements of the fat on your body. Measurements of the thickness of fat under your skin will be taken at the back and front of the upper arm, the back of the body, side of the chest, stomach, above the hip, front of the thigh and side of your calf. Fat under the skin will be measured at these locations using skinfold calipers. These calipers press lightly on the skin, and no harm or mark is associated with their use. A measure of stature, weight and circumference of the arm and calf will be collected also.

Initials ____________________

Date ____________________

Ultrasound

You will also be asked to allow a few ultrasonic measures of the fat on your body. These measurements use high frequency sound that is reflected from different tissues in your body; it is similar in principle to sonar used to detect submarines. Ultrasonic measurements are not painful; they are not radioactive, and there is no risk associated with their use for this purpose. Ultrasonic measurements will be made at the following places on your body: the front and back of the upper arm, the front of the thigh, the side of the calf, the front, back and side of the chest, the stomach and from the buttocks.

Initials ____________________

Date ____________________

Bioelectric Impedance

We wish to measure the amount of water in your body by means of bioelectrical impedance. A very small electric current will be passed through your body, and the resistance or impedance of your body to this current will be measured. There is no feeling or sensation associated with this test. You will not receive an electrical shock. Two electrodes will be attached to your right hand and two to your right foot. Wires will be attached to the electrodes and your body's impedance measured. You will lie down during this procedure which takes less than five minutes. There are no known risks associated with this procedure.

Initials ____________________

Date ____________________

Underwater Weight and Residual Volume

In order to measure the residual volume of your lungs you will be asked to insert a breathing tube in your mouth, clip your nostrils, and breath oxygen in and out several times. It will not be difficult, and you will be able to practice before the measurement. This procedure will determine how much air remains in your lungs when you have fully exhaled. This will take about five minutes.

For the underwater weight, you will need to sit quietly in a special chair suspended from a scale so that your head is just above the water surface. You will exhale all the air you can and lean forward while holding on to the chair and completely submerge your head. You must hold this position, at the most, for 15 seconds while your weight is read from the scale. You will need to repeat the maneuver about ten times for each observer to ensure an accurate weight reading.

The underwater weight will be performed in a tank of warm water about 4 feet deep, but you do not need to know how to swim, and trained researchers will always be there to help you in and out of the tank. You will get a chance to practice this procedure until you feel secure about doing it. There is little risk associated with these procedures.

Initials ____________________

Date ____________________

All of these procedures will take about 1 hour and will be conducted on the same day with as little inconvenience to you as possible. You will be paid $20.00 to partially compensate you for your time. These tests will not necessarily benefit you directly, but they will provide important data that will increase our understanding of the distribution of fat in normal individuals. This will lead to improved treatment of those with problems of fatness. All the data gathered about you will be treated confidentially. At the end of the study, you will receive a statement regarding your body fatness level. If any questions arise concerning these procedures at a later time, please call Dr. Cameron Chumlea, 513-767-7324.

Reasonable and immediate medical attention, as exemplified by the services of the Wright State University Student Health Center, will be provided for physical injury caused directly by participating in these procedures. Any financial compensation for such physical injury will be at the option of Wright State University and decided on a case-by-case basis. Additional information can be obtained from the Manager of Insurance, 873-2566.

CONSENT OF PARTICIPANT

I have read and understand the above information, and all my questions regarding these procedures have been answered. I further understand that I may withdraw from participation in these procedures at any time. My signature on this form in no way obligates me to participate; it is simply a statement of my present intention to participate in those procedures I have initialled as of this date, and that the details of the procedures, including risks and benefits, have been explained and that I understand them.

______________________________ ______________________________

Witness — Signature of Participant

______________________________ ______________________________

Investigator — Date

Informed Consent

Fels Research Institute

Menstrual Variation

Please read all of this statement before signing or initialling any of the spaces provided. Your consent does not obligate you to participate, but is a simple statement of your intention to participate.

Description of Procedures

Our purpose in this research is to determine if measures of fat in the human body change in relation to the menstrual cycle. Valid measures of the human body are needed so that accurate assessments of nutritional status can be made.

In order to measure your body, you may be asked to wear loose clothing and no jewelry. These measurements will be made in a private place. There will be no undressing required.

Bioelectric Impedance

We wish to measure the amount of water in your body by means of bioelectrical impedance. A very small electric current will be passed through your body, and the resistance or impedance of your body to this current will be measured. There is no feeling or sensation associated with this test. You will not receive an electrical shock. Two electrodes will be attached to your right hand and two to your right foot. Wires will be attached to the electrodes and your body's impedance measured. You will lie down during this procedure which takes less than five minutes. There are no known risks associated with this procedure.

This procedure will be conducted once at a mutually agreed upon but fixed time of day, each day for 35 days. This includes Saturdays, Sundays and holidays. During this time you will be asked to keep a diary of your daily activities. You will receive $10.00 a day to partially compensate you for your time.

These tests will not necessarily benefit you directly, but they will provide important data that will increase our understanding of the distribution of fat in normal individuals. This will lead to improved treatment of those with problems of fatness. All the data gathered about you will be treated confidentially. If any questions arise concerning these procedures at a later time, please call Dr. Cameron Chumlea, 513-767-7324.

Reasonable and immediate medical attention, as exemplified by the services of the Wright State University Student Health Center, will be provided for physical injury caused directly by participating in these procedures. Any financial compensation for such physical injury will be at the option of Wright State University, and decided on a case-by-case basis. Additional information can be obtained from the Manager of Insurance, 873-2566.

CONSENT OF PARTICIPANT

I have read and understand the above information, and all my questions regarding these procedures have been answered. I further understand that I may withdraw from participation in these procedures at any time. My signature on this form in no way obligates me to participate; it is simply a statement of my present intention to participate in those procedures, including its risks and benefits, have been explained, and that I understand them.

______________________________	______________________________
Witness	Signature of Participant
______________________________	______________________________
Investigator	Date

GYNECOLOGICAL HEALTH QUESTIONNAIRE

U.S. ARMY BODY COMPOSITION STUDY

DIVISION OF HUMAN BIOLOGY

NAME: ______________________ #: ______________

VISIT DATE: ______________ AGE: __________

BIRTHDATE: ______________ SEX 2

RACE: ________

1. Are you still having menstrual periods ? Yes _______ No _______

   A. If your answer is no, when did you have your last period ?

      Month_____ day_____ year_____

   B. If your answer is yes, is there any irregularity in the onset or length of your period ? Yes _______ No _______

      1. If yes, please explain.

   C. If your answer is yes, is the amount of menstrual flow (circle correct answer)

      very light light moderate heavy very heavy

   D. If your answer is yes, do you experience any pain or discomfort during your period ? Yes _______ No _______

      1. If yes, please explain.

2. Have you experienced any bleeding between your periods ?

   Yes _______ No _______

   A. If your answer is yes, please circle the appropriate word.

      When: seldom occasionally frequently

      Amount: spotting light moderate heavy

3. Are you now, or in the past, have you used or taken any of the following ?

A. IUD: Yes _______ No _______

1. Date started: Month_____ day_____ year_____

2. Date stopped: Month_____ day_____ year_____

3. Why did you stop ?

4. Kind or brand name ______________________________________

B. Oral contraceptive: Yes _____ No _____

1. Date started: Month_____ day_____ year_____

2. Date stopped: Month_____ day_____ year_____

3. Why did you stop ?

4. Kind or brand name ______________________________________

C. Estrogens or other hormones following menopause.

Yes _______ No _______

1. Date started: Month_____ day_____ year_____

2. Date stopped: Month_____ day_____ year_____

3. Why did you stop ?

4. Kind or brand name ______________________________________

4. Do you experience any of the following that are associated with your menstrual cycle ?

A. Water retention Yes _______ No _______

1. If yes, please explain.

B. Weight gain Yes _______ No _______

1. If yes, please explain.

C. Change in breast size, discomfort or condition Yes ____ No ___

1. If yes, please explain.

D. Hot flashes Yes _______ No _______

1. If yes, please explain.

E. Vaginal changes Yes _______ No _______

1. If yes, please explain.

5. Is there any other information about your gynecological health in the past 6 months that you wish to have placed in your records ?

DIVISION OF HUMAN BIOLOGY

ALCOHOL AND TOBACCO CONSUMPTION

________Participant Number   ________________Visit Date   X = Unknown

___ 1. How frequently do you drink? (If you answer "0" please go to No. 6)

0=never   1=a few times per year   2=about once a month

3=about once a week   4=almost every day

___ 2. About how much do you drink on these occasions? (A drink equals a whole bottle of beer, a 4 oz. glass of wine, 1 oz. of liquor, or 1 cocktail or mixed drink).

0=less than a full drink. Give number of drinks.

How often do you drink the following?

0=never   1=occasionally   2=about half the time   3=usually

___ 3. beer

___ 4. wine

___ 5. liquor (mixed drink or cocktail)

___ 6. Have you ever regularly smoked cigarettes during any period of your life, aside from possibly trying them a few times? (If you answer is "0" please go to question No. 17).

0=no   1=yes

___ 7. Do you currently smoke?

0=no   1=yes

___ 8. How many years of your life have you smoked cigarettes in any amount?

1=under 1 or 1, 2=2, 3=3, etc.

___ 9. At what age did you first become a daily cigarette smoker?

(years of age)

___10. Have you smoked for at least one year during the past two years?

0=no   1=yes

___11. What is the approximate number of cigarettes you currently smoke every day (20 per pack)?

___ 12. What type of cigarettes do you smoke? 0=filtered 1=nonfiltered

___ 13. Size 1=regular 2=king 3=100mm

___ 14. Tar 0=low tar 1=high tar

___ 15. When you smoke cigarettes, how deeply do you usually draw in the smoke?

0=draw into mouth or just puff
1=inhale only a few puffs of each cigarette
2=inhale only a few puffs of some cigarettes
3=inhale almost every puff of each cigarette

___ 16. How much of your cigarette burns without your smoking it?

0=a great deal 1=a moderate amount 2=very little

___ 17. Do you frequent or work in an environment (including your household) where many people smoke? 0=no 1=yes

___ 18. Do you smoke a pipe? (If your answer is "0" then go to question No. 22).

0=no 1=yes

___ 19. How often do you smoke a pipe? (give number of times daily)

___ 20. With pipes, how deeply do you inhale?

0=do not inhale 1=partly into the chest 2=deeply into the chest

___ 21. With pipes, how often do you inhale?

0=not usually 1=a few puffs from each pipe 2=most puffs from each pipe

___ 22. Do you smoke cigars? 0=no 1=yes

___ 23. How often do you smoke cigars? (give number of times per day)

___ 24. With cigars, how deeply do you inhale?

0=do not inhale 1=partly into the chest 2=deeply into the chest

___ 25. With cigars, how often do you inhale?

0=not usually 1=a few puffs from each cigar 2=most puffs from each cigar

___ 26. Do you currently use any of the following regularly:

Chewing tobacco (give number/day)
Snuff (give number/day)

DIVISION OF HUMAN BIOLOGY
Department of Pediatrics
Anthropometry Data Sheet
Fels Longitudinal Study

No____________________

Name____________________ Date____________________

Birthdate____________________ Age____________________

	A	B	A	B
Wt. in Kg.(-.1)				
Recumbent length				
Sitting height(-.50)				
Standing height				
Chest circum.				
Abdominal circum.				
Calf circum.				
Elbow breadth				
Bicristal breadth				
Arm circum.				
Skinfold jaw				
Skf. triceps				
Skf. subscap.				
Skf. biceps				
Skf. ant. chest				
Skf. midax. h.				
Skf. suprailiac				
Skf. lat. calf				
Knee breadth				
Biacromial breadth				
Head circum.				

MENSTRUAL VARIATION QUESTIONNAIRE

(TO BE ANSWERED DAILY)

NAME: ______________________ #: ____________

VISIT DATE: ______________ AGE: ________

BIRTHDATE: ______________ SEX: ______ RACE: ______

TIME: HOUR MINUTE A.M.

_____ _____ P.M.

INTERVAL FROM LAST DRINK: ______________ (HR.)

INTERVAL FROM LAST MEAL : ______________ (HR.)

1. Is what you ate yesterday the way you normally eat ?

   1 = YES ________ 2 = NO ________

2. In what way was what you ate yesterday different from usual ?

____

____

Please check any of the following drugs or medications which you have taken in the past 24 hours and indicate the amount taken and the number of hours which have elapsed since you last took it.

	YES = 1 NO = 2	Specify	HRS.	AMT.
_____	Aspirin, Bufferin, etc.	__________	____	____
_____	Aspirin substitute (Tylenol)	__________	____	____
_____	Stronger pain reliever (Darvon, Excedrin, etc.)	__________	____	____
_____	Laxatives	__________	____	____
_____	Medicine for indigestion	__________	____	____

YES = 1 NO = 2

		Specify	HRS.	AMT.
______	Tranquilizers	______	___	___
______	Sleeping pills	______	___	___
______	Pep pills (Dexadrine, amphetamines, "uppers")	______	___	___
______	Beer	______	___	___
______	Wine	______	___	___
______	Liquor	______	___	___
______	Coffee (not de-caffeinated)	______	___	___
______	Tea	______	___	___
______	Chocolate	______	___	___
______	Cola (Pepsi, Coke, RC,etc.)	______	___	___
______	Diet pills	______	___	___
______	Other non-prescription medicine or stimulant	______	___	___
______	Vitamins	______	___	___

Have you taken any other prescription medicine in the past 24 hours?

______	Digitalis (heart pills)	______	___	___
______	Nitrites (nitroglycerine)	______	___	___
______	Quinidine or proanamide	______	___	___
______	Diuretics (water pills)	______	___	___
______	Hypotensives	______	___	___
______	Thyroid	______	___	___
______	Anti-thyroid	______	___	___
______	Anticoagulants	______	___	___
______	Antibiotics	______	___	___
______	Insulin	______	___	___
______	Other, specify ______	______	___	___

MENSTRUAL VARIATION QUESTIONNAIRE

(THE FOLLOWING QUESTIONS NEED TO BE ANSWERED THE FIRST DAY ONLY)

NAME: ____________________ #: ____________

VISIT DATE: ____________________ AGE: ____________

BIRTHDATE: ____________________ SEX: 2

RACE: ____________

1. HANDEDNESS (RE: HEAVY PHYSICAL ACTIVITY)

1 = LEFT ______

2 = RIGHT ______

3 = BOTH ______

2. SALT ADDITION TO FOOD

FREQUENCY	AMOUNT
(1) NEVER ______	(1) NONE ______
(2) INFREQUENTLY ______	(2) LITTLE ______
(3) FREQUENTLY ______	(3) MODERATE ______
(4) ALWAYS ______	(4) HEAVY ______

3. ARE YOU ON A SPECIAL DIET ?

1 = YES ______

2 = NO ______

4. WHAT KIND OF DIET IS IT.? (CHECK ALL THAT APPLY)

HIGH PROTEIN .... ______

HIGH CALORIE .... ______

LOW FAT .... ______

LOW PROTEIN .... ______

LOW SALT .... ______

LOW CARBOHYDRATES .... ______

LOW SUGAR .... ______

LOW CALORIE .... ______

LOW CHOLESTEROL .... ____________

VEGETARIAN WITH EGGS, MILK, ETC. .... ____________

VEGETARIAN WITH NO EGGS, MILK, ETC. .... ____________

A BLAND DIET .... ____________

SOME OTHER TYPE .... ____________

IF "OTHER TYPE" DESCRIBE: ____

____

5. HOW LONG HAVE YOU BEEN ON THIS DIET ? SPECIFY HOW MANY WEEKS, MONTHS, OR YEARS

WEEKS: ________

MONTHS: ________

YEARS: ________

6. WAS THIS DIET PRESCRIBED BY A HEALTH PROFESSIONAL, SUCH AS A DOCTOR, DIETICIAN OR NURSE ?

1 = YES ________

2 = NO ________

7. DO YOU GO OFF THIS DIET OFTEN, ONCE IN A WHILE, RARELY OR NEVER ?

1 = OFTEN ________

2 = ONCE IN A WHILE ________

3 = RARELY OR NEVER ________

8. HAS YOUR WAY OF EATING CHANGED IN THE PAST THREE MONTHS ?

1 = YES ________

2 = NO ________

IF "NO," THEN STOP.

9. HOW HAS YOUR WAY OF EATING CHANGED ? ________________________________

____

FORM F

MENSTRUAL VARIATION

U.S. ARMY CONTRACT DAAK-60-84-C-0054 (1984)

NAME: ______________________ #: ______________

BIRTHDATE: ______________

RACE: ______________

AGE: ______________

SEX: 2

START DATE ______________

ORAL CONTRACEPTIVE YES ______ NO ______

BRAND USED ______________

DAYS USED (FROM ______________ THROUGH ______________)

DATE OF LAST DOSAGE ______________

	DATE	TIME	IMPEDANCE	MENSES (YES/NO)	COMMENTS
01					
02					
03					
04					
05					

FORM F (CONTINUED)

MENSTRUAL VARIATION

U.S. ARMY CONTRACT DAAK-60-84-C-0054 (1984)

DATE	TIME	IMPEDANCE	MENSES (YES/NO)	COMMENTS
06 ____	____	____	____	____
07 ____	____	____	____	____
08 ____	____	____	____	____
09 ____	____	____	____	____
10 ____	____	____	____	____
11 ____	____	____	____	____
12 ____	____	____	____	____
13 ____	____	____	____	____
14 ____	____	____	____	____
15 ____	____	____	____	____
16 ____	____	____	____	____
17 ____	____	____	____	____
18 ____	____	____	____	____
19 ____	____	____	____	____
20 ____	____	____	____	____
21 ____	____	____	____	____

FORM F (CONTINUED)
MENSTRUAL VARIATION
U.S. ARMY CONTRACT DAAK-60-84-C-0054 (1984)

	DATE	TIME	IMPEDANCE	MENSES (YES/NO)	COMMENTS
22					
23					
24					
25					
26					
27					
28					
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31					
32					
33					
34					
35					

APPENDIX B

ANTHROPOMETRIC, ULTRASONIC, AND BIOELECTRIC IMPEDANCE MEASUREMENT TECHNIQUES

Anthropometry

In the present study, two observers were employed, with limits specified for intra- and inter-observer differences. Measurements were repeated if these limits were exceeded. If the intra- or inter-observer difference for the second pair of measurements was within the specified limits, the mean of the second pair of measurements was recorded as the observed value for the variable. If the intra- or inter-observer difference for the second pair of measurements from a participant was again outside the limits, the mean of all four measurements was recorded as the observed value for that variable. All the original measurements were retained for possible further analyses.

Resolving intra- or inter-observer differences that exceeded pre-set limits reduced the prevalence of large inter-observer errors. When the means of four measurements that were not in agreement were used, the variation between participants was reduced.

The following measurements were taken with the participant standing.

Weight. A bathing suit or shorts for men and shorts and a halter for women were worn when weight was measured and 0.1 kg was subtracted from the measured weight to adjust for this. For the measurement of weight, the participant stood in the center of the scale platform with his/her weight equally distributed on both feet and with no other part of the body in contact with the scales. Each observer took one measurement; the paired measurements agreed within 0.1 kg or were repeated. Weight was recorded to the nearest 0.1 kg.

Stature. The measurement of stature required two observers. One positioned the anthropometer in the sagittal plane just posterior to the participant and the second checked the position of the anthropometer and recorded the participant's stature. The first observer (standing upon a stool if necessary) placed the base of the anthropometer about 10 cm posterior to the participant, with the sliding arm above the participant's head. This observer positioned the anthropometer behind the participant so that it was vertical in a coronal plane. The second observer, using a plumb bob, instructed the first so that the anthropometer was held vertically in the sagittal plane of the participant. The second observer instructed the participant to "stand up straight" and adjusted the participant's head so that a line from the lower edge of the left orbit (orbitale) to the upper margin of the left external auditory meatus (tragion) was parallel to the floor (Frankfort plane). The second observer asked the participant to hold a deep breath, and lowered the sliding arm of the anthropometer until it was in firm contact with the most superior point on the participant's head (vertex) and recorded the stature measurement. Firm pressure on the sliding arm was needed to compress hair. Stature was recorded to the nearest 0.1 cm. The limits for observer errors were 1.0 cm.

Arm Circumference. The participant, while standing, flexed the right arm at the elbow to a 90° angle with the palm of the hand upwards. The insertion tape was placed between the posterior part of the acromion of the scapula (acromiale) and the point of the olecranon process at the elbow over the posterior portion of the upper arm, with the side of the tape that has a solid triangle facing the observer. The tape was moved up and down on the posterior surface of the upper arm until the number on the tape at the acromion matched the number at the olecranon. The solid triangle on the tape then indicated the midpoint of the upper arm. The other observer marked this level with a pencil or felt pen.

The tape was then placed around the upper arm directly over the mark, with the tape parallel to the floor. With the arm hanging normally at the side and the muscles relaxed, the tape was pulled around the arm so as to ensure contact with the total circumference, but not tightly enough to compress the skin. The measurement was recorded to the nearest 1.0 mm and repeated if observers differed by more than 2.0 mm.

Calf Circumference. The participant stood with the feet slightly apart and the weight evenly distributed between the two feet. The tape was placed around the left calf at its maximum circumference, keeping the tape parallel to the floor. Several readings at various locations were taken until the level of the maximum circumference was located. The tape was in contact with the total circumference, but not tight enough to indent the skin. With a pencil or felt pen, a small mark was placed just proximal to the tape in the midline of the lateral aspect of the calf. The measurement was recorded to the nearest 1.0 mm, and repeated if the observers differed by more than 2.0 mm.

Skinfolds

All skinfolds were measured with a Lange caliper. The thumb and index fingers were used to grasp a fold of skin and subcutaneous fat. The amount of subcutaneous fat and skin grasped depended upon the thickness of the subcutaneous fat. The observer grasped just enough skin and fat to form a fold that separated from the underlying muscle. The sides of the fold were approximately parallel. The skinfold was grasped about 1.0 cm proximal to the site at which the skinfold was to be measured. The jaws of the caliper were applied about 1.0 cm distal to the fingers and perpendicular to the long axis of the skinfold. The left hand held the skinfold in place until after the measurement had been taken. The caliper was read about 3 seconds after the caliper tension was released from a position that minimized parallax. Skinfold measurements were recorded to the nearest 0.5 mm. When observers differed by more than the specified limits for individual skinfolds, additional measurements were made.

Triceps Skinfold. The triceps skinfold was measured at the level marked for the arm circumference on the subject's upper arm as it hung at the side. The palm of the subject's hand was turned toward the body. To measure this skinfold, the observer grasped a vertical fold of skin on the posterior surface of the arm just proximal to the mark used to indicate the level for the measurement of arm circumference. It is important that the fold be in the midline of the arm on a plane directly posterior to the maximum bulge of the triceps. When disagreement between observers exceeded 5.0 mm, the measurements were repeated.

Biceps Skinfold. The same procedure was followed as for the triceps skinfold, but the measurement was taken on the anterior aspect of the arm with the palm directed anteriorly. A vertical fold was elevated and the caliper jaws were placed perpendicular to this. The level was the same as for the triceps skinfold and for arm circumference. In robust individuals, it was necessary to rotate the arm slightly or ask the subject to shift it slightly away from the body to measure the skinfold accurately. When disagreement between observers exceeded 5.0 mm, the measurements were repeated.

Subscapular Skinfold. To measure the subscapular skinfold, a fold of skin and subcutaneous fat was elevated on a diagonal directed downward and laterally just inferior and lateral to the inferior angle of the scapula. The caliper jaws were placed perpendicular to the fold. When disagreement between observers exceeded 5.0 mm, the measurements were repeated.

Midaxillary Skinfold. The arm was flexed and held horizontally from the shoulder with the elbow in the midline of the body, close to the anterior aspect of the chest. A vertical skinfold was measured in the lateral midline of the thorax at the level of the xiphoid process. When disagreement between observers exceeded 5.0 mm, the measurements were repeated.

The following skinfolds were measured with the participant supine.

Anterior Thigh Skinfold. This measurement was made on the anterior aspect of the thigh with the leg flat on the bed or couch. Thigh length was measured from the anterior superior iliac spine to the proximal border of the patella. A point proximal to the patella by a distance equal to 1/3 of the length of the thigh was located and marked. A skinfold with its long axis proximo-distal was picked up in the midline of the anterior aspect of the thigh at the marked level. The caliper jaws were applied perpendicular to the skinfold. When the observers differed by more than 3.0 mm, the measurements were repeated.

Lateral Calf Skinfold. The measurement was taken at the level of the pencil mark (see Calf Circumference) in the midline of the lateral aspect of the calf. The leg was raised so that the ankle and knee were each bent at a 90° angle but the foot remained on the surface of the bed or couch. In some individuals the skin was tight around the calf and it was difficult to pick up a skinfold. When the observers differed by more than 5.0 mm, the measurements were repeated.

Paraumbilical Skinfold. This measurement was taken at a marked point 4.0 cm from the center of the umbilicus on a line from the umbilicus to the anterior superior iliac spine. A skinfold was picked up about 1 cm distal to the mark. The fold of skin was parallel to the midline of the body, and the calipers were applied perpendicular to the fold. When the observers differed by more than 3.0 mm, the measurements were repeated.

Ultrasound

There are several important points to note in using the EchoScan 1502 ultrasound machine. For all ultrasonic measurements, the observer applied the ultrasonic gel to the proper point on the participant. The emitting-receiving surface of the transducer was then positioned flush and perpendicular to this surface without compression of the tissues. The whole dark surface of the transducer had to be in contact with the skin. Consequently, a flat body surface at least 0.8 cm wide was necessary for an accurate measurement. When holding the transducer, care was taken to ensure that the surface tension among the probe, the aquasonic gel and the skin did not raise the level of the skin. The observer holding the transducer informed the observer reading the EchoScan when the measurement could be recorded. Where possible, the observer with the transducer was positioned so that the participant's body helped to steady the hand holding the transducer, but it was the responsibility of both observers to ensure the transducer was properly positioned. When the observer holding the transducer was ready, he or she indicated this to the observer reading the EchoScan. This second observer adjusted the gain and recorded the reading. This procedure of positioning the transducer and recording the reading from the EchoScan was the same for all the ultrasonic measurements.

The following measurements were made with the participant standing.

Triceps. The participant stood in the same position as for the triceps skinfold measurement. The ultrasonic measurement was made at the site of the triceps skinfold.

Biceps. For this measurement, the arm was positioned as for the biceps skinfold measurement and the ultrasonic measurement was made at the same site as the biceps skinfold.

Subscapular. The participant remained in the same position as for the triceps ultrasonic measurement. The transducer was positioned perpendicular to the skin just inferior and lateral to the inferior angle of the scapula.

Midaxillary. This measurement was taken at the point marked for the midaxillary skinfold. The participant was instructed to hold his/her breath while the measurement was being made.

For the following measurements, the participant was positioned supine.

Anterior Thigh. For this measurement, the leg was positioned as for measuring the anterior thigh skinfold. The ultrasonic measurement was made at the same site as the anterior thigh skinfold.

Lateral Calf. For this measurement, the leg was positioned as for the lateral calf skinfold. The transducer was placed against the lateral surface of the calf at the site where the lateral calf skinfold was measured.

Paraumbilical. This measurement was taken at the point (marked) where the paraumbilical skinfold was measured. The participant was instructed to hold his/her breath when the measurement was being made.

Breast. The breast measurement was taken with the transducer placed so that its edge was tangential to the proximal margin of the areola. The participant was instructed to stop breathing while this measurement was taken.
This measurement did not present a problem in men unless there was a large amount of hair on the chest. When this was so, it was noted. In older women, this measurement can present problems if the breasts are pendulous. If the breast does not remain positioned on the anterior surface of the chest, this measurement should not be taken. This did not occur in the present study.

Buttocks. The participant must lie prone for this measurement. This measurement was taken 7 cm distal to the midpoint of the distance between the anterior superior iliac spine and the midline of the posterior aspect of the trunk. It may be necessary to hold the participant's clothing away from the body to make this measurement.

Bioelectric Impedance

Bioelectric resistance was measured with an RJL Systems Model BIA-101 Bioelectric Impedance Analyzer. Resistance was measured twice on the right side of the body of each participant by each of two observers working independently. Resistance was measured also on the left side of the body in a random sample of participants by two observers working independently.

For the right-sided pair of resistance measures, the participant was supine with the arms resting alongside but not touching the body, and the legs were separated so that there was no contact between the thighs. The red electrode of the red cable was attached to the posterior surface of the right wrist midway between the distal condyles of the radius and ulna. The black electrode of the red cable was attached to the posterior surface of the right hand over the distal end of the third metacarpal. The red electrode of the black cable was attached to the anterior surface of the right ankle midway between the malleoli of the tibia and fibula. The black electrode of the black cable was attached to the anterior surface of the right foot midway between the distal ends of the second and third metatarsals. Each electrode was attached using a very small amount of electrode cream and aproximately 4 cm of electrode tape.

A single measure of resistance was recorded by each observer. After the first pair of resistance measurements, the electrodes were removed and the participant stood for measures of stature and weight. For the next pair of resistance measurements, the participant again reclined to a supine position, and the electrodes were attached as explained above. Again, measures of resistance were recorded by each observer. If a resistance measure was also to be recorded from the left side of a participant, the participant was again asked to stand. The particpant then assumed a supine position and the electrodes were attached to the left side of the body in positions that corresponded to those for the right-sided measurements. A single measure of resistance using right-sided electrode sites was recorded by each observer. A test object was measured at the beginning and at the end of the measurements each day.

APPENDIX C

EQUATIONS FOR PREDICTING BODY COMPOSITION IN MEN AND WOMEN FROM ANTHROPOMETRY AND STATURE^2/RESISTANCE

TABLE C-1. Prediction of Body Density by Multiple Regression Analysis in Men (Stature^2/Resistance Forced in).

$R^2 = 0.61$ N = 93 C(p) = 1.80

Adjusted $R^2 = 0.60$ Root mean squared error = 0.009 gm/cm^3

Independent Variables	Regression Coefficient	Standard Error of Regression Coefficient	Variance Inflation
Intercept	1.12949289		
Stature^2/Resistance (cm^2/ohm)	0.00135950	0.00018689	2.57
Weight (kg)	-0.00110069	0.00016992	4.11
Calf circumference (cm)	-0.00203003	0.00063614	3.53

TABLE C-2. Prediction of Percent Body Fat by Multiple Regression Analysis in Men (Stature^2/Resistance Forced in).

$R^2 = 0.62$ N = 93 C(p) = 1.77

Adjusted $R^2 = 0.60$ Root mean squared error = 4.002 gm/cm^3

Independent Variables	Regression Coefficient	Standard Error of Regression Coefficient	Variance Inflation
Intercept	-13.84619706		
Stature^2/Resistance (cm^2/ohm)	-0.60535346	0.08197500	2.57
Weight (kg)	0.48547367	0.07453287	4.11
Calf circumference (cm)	0.91340414	0.27902592	3.53

TABLE C-3. Prediction of Total Body Fat by Multiple Regression Analysis in Men (Stature^2/Resistance Forced in).

R^2 = 0.76	N = 93	C(p) = 1.42	
Adjusted R^2 = 0.76	Root mean squared error = 3.143 kg		
Independent Variables	Regression Coefficient	Standard Error of Regression Coefficient	Variance Inflation
Intercept	-26.07706814		
Stature^2/Resistance (cm^2/ohm)	-0.51552737	0.06436342	2.57
Weight (kg)	0.53783046	0.05852017	4.11
Calf circumference (cm)	0.88249943	0.21907977	3.53

TABLE C-4. Prediction of Fat Free Mass by Multiple Regression Analysis in Men (Stature^2/Resistance Forced in).

R^2 = 0.82	N = 93	C(p) = 1.42	
Adjusted R^2 = 0.83	Root mean squared error = 3.143 kg		
Independent Variables	Regression Coefficient	Standard Error of Regression Coefficient	Variance Inflation
Intercept	26.07706814		
Stature^2/Resistance (cm^2/ohm)	0.51552737	0.06436342	2.57
Weight (kg)	0.46216954	0.05852017	4.11
Calf circumference (cm)	-0.88249943	0.21907977	3.53

TABLE C-5. Prediction of Body Density by Multiple Regression Analysis in Women (Stature^2/Resistance Forced in).

$R^2 = 0.71$	$N = 79$	$C(p) = 5.29$	
Adjusted $R^2 = 0.68$	Root mean squared error = 0.008 gm/cm^3		
Independent Variables	Regression Coefficient	Standard Error of Regression Coefficient	Variance Inflation
Intercept	1.15255424		
Stature^2/Resistance (cm^2/ohm)	0.00180991	0.00023403	2.10
Weight (kg)	-0.00067281	0.00026042	5.98
Calf circumference (cm)	-0.00261901	0.00062148	3.07
Arm circumference (cm)	-0.00179223	0.00061161	3.20
Age (yr)	-0.00061409	0.00030491	1.02

TABLE C-6. Prediction of Percent Body Fat by Multiple Regression Analysis in Women (Stature^2/Resistance Forced in).

$R^2 = 0.71$	$N = 79$	$C(p) = 5.32$	
Adjusted $R^2 = 0.69$	Root mean squared error = 3.893%		
Independent Variables	Regression Coefficient	Standard Error of Regression Coefficient	Variance Inflation
Intercept	-26.07422971		
Stature^2/Resistance (cm^2/ohm)	-0.82968782	0.10738577	2.10
Weight (kg)	0.31566325	0.11949490	5.98
Calf circumference (cm)	1.19657036	0.28517193	3.07
Arm circumference (cm)	0.82659503	0.28064643	3.20
Age (yr)	0.28584212	0.13991217	1.02

TABLE C-7. Prediction of Total Body Fat by Multiple Regression Analysis in Women (Stature^2/Resistance Forced in).

R^2 = 0.85	N = 79	C(p) = 5.92	
Adjusted R^2 = 0.84	Root mean squared error = 2.612 kg		
Independent Variables	Regression Coefficient	Standard Error of Regression Coefficient	Variance Inflation
Intercept	-35.16835290		
Stature^2/Resistance (cm^2/ohm)	-0.54619901	0.07205520	2.10
Weight (kg)	0.53274609	0.08018036	5.98
Calf circumference (cm)	0.67882700	0.19134864	3.07
Arm circumference (cm)	0.56116341	0.18831206	3.20
Age (yr)	0.21782532	0.09388022	1.02

TABLE C-8. Prediction of Fat Free Mass by Multiple Regression Analysis in Women (Stature^2/Resistance Forced in).

R^2 = 0.77	N = 79	C(p) = 5.92	
Adjusted R^2 = 0.75	Root mean squared error = 2.612 kg		
Independent Variables	Regression Coefficient	Standard Error of Regression Coefficient	Variance Inflation
Intercept	35.16835290		
Stature^2/Resistance (cm^2/ohm)	0.54619901	0.07205520	2.10
Weight (kg)	0.46725391	0.08018036	5.98
Calf circumference (cm)	-0.67882700	0.19134864	3.07
Arm circumference (cm)	-0.56116341	0.18831206	3.20
Age (yr)	-0.21782532	0.09388022	1.02

APPENDIX D

DISTRIBUTION STATISTICS

Distribution statistics, based on the means of all recorded measurements, are presented for each sex for anthropometric variables, for variables related to underwater weighing and for resistance. Statistical tests were not made of the possible significance of differences between the means for the two sexes or of the normality of all the distributions. The comments that follow refer to trends and not to differences shown to be statistically significant.

The anthropometric variables all had larger mean values in men than in women, and all, with the exception of stature, had larger standard deviations (SD) in the men than in the women. The mean values for skinfold thicknesses were larger for the women than for the men. Also, the SDs for women's skinfolds were larger than those for the men. The means for the ultrasonic measurements were also larger in the women than in the men. The largest mean for the men was that for the buttocks site, but the paraumbilical site had the largest mean for the women. In each sex, the smallest mean was for the biceps site. The SD values for the ultrasonic measures were generally larger for the women than for the men.

Men had larger means and SD for underwater weight, RV, BD, and FFM than women, but smaller values for %BF and TBF. The data for the underwater weights (10 per participant) showed a tendency for the first three weights to be lower than the others, but there was little change in either sex among the later underwater weights. Men tended to have smaller mean bioelectric resistance values than women, but their SDs tended to be larger than those for the women.

Comparisons of distribution statistics between whites and blacks can be made for men, but there were too few black women to allow corresponding comparisons between black and white women. For men, there were only small differences between blacks and whites in the mean values for anthropometric variables and skinfold thicknesses, but the ultrasonic values were all larger in the whites than in the blacks, except for the measurements made at the lateral calf site. The means for underwater weights, resistance and FFM tended to be larger for the blacks than for the whites, but RV and %BF tended to be larger in the whites than in the blacks.

The mean stature of the women tended to be greater than that for the most recent Army anthropometric surveys (96), but the SD values tended to be less. In both men and women, the mean weights and the SD values were slightly greater in the present study than in the Army surveys.

TABLE D-1. Distribution Statistics for Anthropometry, Ultrasound and Body Composition Variables in All Men.

Variables	N	Mean	SD	SE of Mean
Anthropometry				
Stature (cm)	93	176.8	5.8	0.6
Weight (kg)	93	74.9	11.4	1.2
Arm Circumference (cm)	93	32.2	3.6	0.4
Calf Circumference (cm)	93	37.1	2.8	0.3
Skinfolds (mm)				
Triceps	93	10.6	5.1	0.5
Subscapular	93	12.1	6.1	0.6
Biceps	93	4.7	2.6	0.3
Midaxillary	93	9.6	5.4	0.6
Paraumbilical	92	16.9	9.9	1.0
Anterior Thigh	91	11.7	5.4	0.6
Lateral Calf	90	8.1	3.5	0.4
Ultrasound (mm)				
Triceps	84	5.4	1.5	0.2
Subscapular	84	5.5	1.7	0.2
Biceps	84	3.5	1.4	0.2
Midaxillary	84	5.2	1.8	0.2
Breast	84	6.0	1.9	0.2
Paraumbilical	83	6.3	2.2	0.2
Anterior Thigh	84	5.7	1.8	0.2
Lateral Calf	84	4.0	1.3	0.1
Buttocks	80	6.7	1.9	0.2
Body Composition				
Mean of 3 highest Underwater Weights (kg)	93	3.6	0.8	0.1
Residual Lung Volume (L)	93	1.3	0.4	0.0
Body Density (gm/cm^3)	93	1.1	0.0	0.0
Percent Body Fat (%)	93	14.8	6.3	0.7
Total Body Fat (kg)	93	11.5	6.4	0.7
Fat Free Mass (kg)	93	63.4	7.6	0.8
Resistance (ohm)	93	459.5	49.8	5.2

TABLE D-2. Distribution Statistics for Anthropometry, Ultrasound and Body Composition Variables in All Women.

Variables	N	Mean	SD	SE of Mean
Anthropometry				
Stature (cm)	83	164.3	5.8	0.6
Weight (kg)	83	61.2	10.0	1.1
Arm Circumference (cm)	83	28.2	2.8	0.3
Calf Circumference (cm)	84	35.7	2.7	0.3
Skinfolds (mm)				
Triceps	84	18.5	6.0	0.7
Subscapular	83	13.6	7.1	0.8
Biceps	83	7.8	4.4	0.5
Midaxillary	83	11.0	5.3	0.6
Paraumbilical	82	22.5	10.5	1.1
Anterior Thigh	72	25.3	7.5	0.9
Lateral Calf	75	14.8	4.7	0.5
Ultrasound (mm)				
Triceps	82	7.4	2.2	0.2
Subscapular	81	6.4	1.9	0.2
Biceps	82	4.5	1.6	0.2
Midaxillary	82	6.1	1.7	0.2
Breast	81	5.9	2.1	0.2
Paraumbilical	81	7.2	2.4	0.3
Anterior Thigh	81	9.3	2.3	0.3
Lateral Calf	82	5.8	1.6	0.2
Buttocks	77	7.4	2.4	0.3
Body Composition				
Mean of 3 highest Underwater Weights (kg)	81	1.4	0.7	0.1
Residual Lung Volume (L)	83	1.2	0.4	0.0
Body Density (gm/cc)	80	1.0	0.0	0.0
Percent Body Fat (%)	80	26.0	6.9	0.8
Total Body Fat (kg)	80	16.2	6.5	0.7
Fat Free Mass (kg)	80	44.8	5.2	0.6
Resistance (ohm)	82	571.0	62.7	6.9

TABLE D-3. Distribution Statistics for Anthropometry, Ultrasound and Body Composition Variables in White Men.

Variables	N	Mean	SD	SE of Mean
Anthropometry				
Stature (cm)	78	177.0	6.1	0.7
Weight (kg)	78	74.7	11.4	1.3
Arm Circumference (cm)	78	32.1	3.5	0.4
Calf Circumference (cm)	78	37.0	2.8	0.3
Skinfolds (mm)				
Triceps	78	10.4	5.2	0.6
Subscapular	78	11.8	5.4	0.6
Biceps	78	4.8	2.5	0.3
Midaxillary	78	9.5	5.0	0.6
Paraumbilical	77	17.4	9.9	1.1
Anterior Thigh	77	12.1	5.6	0.6
Lateral Calf	76	7.9	3.4	0.4
Ultrasound (mm)				
Triceps	75	5.5	1.6	0.2
Subscapular	75	5.6	1.7	0.2
Biceps	75	3.5	1.4	0.2
Midaxillary	75	5.3	1.8	0.2
Breast	75	6.2	1.9	0.2
Paraumbilical	74	6.5	2.3	0.3
Anterior Thigh	75	5.8	1.8	0.2
Lateral Calf	75	4.0	1.4	0.2
Buttocks	71	6.8	1.9	0.2
Body Composition				
Mean of 3 highest Underwater Weights (kg)	78	3.5	0.8	0.1
Residual Lung Volume (L)	78	1.4	0.4	0.0
Body Density (gm/cm^3)	78	1.1	0.0	0.0
Percent Body Fat (%)	78	14.9	6.4	0.7
Total Body Fat (kg)	78	11.6	6.6	0.7
Fat Free Mass (kg)	78	63.1	7.5	0.8
Resistance (ohm)	78	457.7	45.6	5.2

TABLE D-4. Distribution Statistics for Anthropometry, Ultrasound and Body Composition Variables in Black Men.

Variables	N	Mean	SD	SE of Mean
Anthropometry				
Stature (cm)	15	175.5	4.0	1.0
Weight (kg)	15	75.9	11.5	3.0
Arm Circumference (cm)	15	32.8	4.2	1.1
Calf Circumference (cm)	15	37.8	2.8	0.7
Skinfolds (mm)				
Triceps	15	11.2	5.1	1.3
Subscapular	15	13.4	9.1	2.4
Biceps	15	4.4	3.1	0.8
Midaxillary	15	10.2	7.4	1.9
Paraumbilical	15	14.8	10.2	2.6
Anterior Thigh	14	9.6	2.9	0.8
Lateral Calf	14	9.2	3.9	1.0
Ultrasound (mm)				
Triceps	9	4.6	1.2	0.4
Subscapular	9	4.3	0.9	0.3
Biceps	9	2.7	0.6	0.2
Midaxillary	9	4.4	1.5	0.5
Breast	9	4.7	1.6	0.5
Paraumbilical	9	4.9	1.5	0.5
Anterior Thigh	9	4.9	1.6	0.5
Lateral Calf	9	4.2	1.0	0.3
Buttocks	9	5.9	1.7	0.6
Body Composition				
Mean of 3 highest Underwater Weights (kg)	15	3.9	1.0	0.3
Residual Lung Volume (L)	15	1.1	0.4	0.1
Body Density (gm/cm^3)	15	1.1	0.0	0.0
Percent Body Fat (%)	15	14.5	6.0	1.5
Total Body Fat (kg)	15	11.4	5.5	1.4
Fat Free Mass (kg)	15	64.5	8.4	2.2
Resistance (ohm)	15	469.3	69.0	17.8

TABLE D-5. Distribution Statistics for Anthropometry, Ultrasound and Body Composition Variables in White Women.

Variables	N	Mean	SD	SE of Mean
Anthropometry				
Stature (cm)	75	164.7	5.9	0.7
Weight (kg)	75	60.8	9.2	1.1
Arm Circumference (cm)	75	28.2	2.9	0.3
Calf Circumference (cm)	75	35.6	2.7	0.3
Skinfolds (mm)				
Triceps	75	18.5	6.3	0.7
Subscapular	74	13.5	7.3	0.8
Biceps	74	7.8	4.6	0.5
Midaxillary	74	10.9	5.5	0.6
Paraumbilical	74	22.7	10.2	1.2
Anterior Thigh	66	25.3	7.7	1.0
Lateral Calf	69	14.8	4.7	0.6
Ultrasound (mm)				
Triceps	74	7.5	2.2	0.3
Subscapular	73	6.5	1.9	0.2
Biceps	74	4.5	1.6	0.2
Midaxillary	74	6.1	1.7	0.2
Breast	73	5.9	2.1	0.2
Paraumbilical	73	7.2	2.5	0.3
Anterior Thigh	74	9.4	2.3	0.3
Lateral Calf	74	5.8	1.6	0.2
Buttocks	71	7.5	2.4	0.3
Body Composition				
Mean of 3 highest Underwater Weights (kg)	74	1.4	0.8	0.1
Residual Lung Volume (L)	74	1.2	0.4	0.0
Body Density (gm/cm^3)	73	1.0	0.0	0.0
Percent Body Fat (%)	73	25.9	7.1	0.8
Total Body Fat (kg)	73	16.2	6.7	0.8
Fat Free Mass (kg)	73	44.9	5.1	0.6
Resistance (ohm)	75	572.7	64.1	7.4

TABLE D-6. Distribution Statistics for Anthropometry, Ultrasound and Body Composition Variables in Black Women.

Variables	N	Mean	SD	SE of Mean
Anthropometry				
Stature (cm)	8	161.2	3.3	1.2
Weight (kg)	8	64.9	16.0	5.6
Arm Circumference (cm)	8	28.6	2.5	0.9
Calf Circumference (cm)	9	36.3	3.1	1.0
Skinfolds (mm)				
Triceps	9	18.9	3.5	1.2
Subscapular	9	14.5	4.8	1.6
Biceps	9	7.8	2.4	0.8
Midaxillary	9	11.9	3.9	1.3
Paraumbilical	8	20.5	8.2	2.9
Anterior Thigh	6	25.4	5.4	2.2
Lateral Calf	6	15.2	5.0	2.0
Ultrasound (mm)				
Triceps	8	6.6	1.1	0.4
Subscapular	8	5.7	2.1	0.7
Biceps	8	4.0	0.9	0.3
Midaxillary	8	5.6	1.7	0.6
Breast	8	6.1	2.0	0.7
Paraumbilical	8	6.9	1.3	0.5
Anterior Thigh	7	7.9	1.7	0.6
Lateral Calf	8	5.0	1.2	0.4
Buttocks	6	6.4	2.1	0.9
Body Composition				
Mean of 3 highest Underwater Weights (kg)	7	1.5	0.5	0.2
Residual Lung Volume (L)	9	1.1	0.5	0.2
Body Density (gm/cm^3)	7	1.0	0.0	0.0
Percent Body Fat (%)	7	27.8	4.9	1.8
Total Body Fat (kg)	7	16.7	3.7	1.4
Fat Free Mass (kg)	7	43.2	6.3	2.4
Resistance (ohm)	7	552.9	44.4	16.8

APPENDIX E

EFFECTS OF PHYSIOLOGICAL FACTORS

TABLE E-1. Analysis of Covariance Tests for the Influence of "Physiological Noise Factors" on the Differences between Predictions of Body Density from "Stature^2/Resistance plus Anthropometry" and from Underwater Weighing in Men.

Source of Covariance	df	F-value	P-value
Exercise group	2	1.22	0.301
Interval from last meal	1	1.31	0.255
Interval from last drink	1	0.32	0.573
Test for parallelism			
Interval from last meal by exercise group	2	0.17	0.846
Interval from last drink by exercise group	2	0.29	0.749
Test for nonadditive effect			
Interval from last meal by Interval from last drink	1	0.29	0.593

TABLE E-2. Analysis of Covariance Tests for the Influence of "Physiological Noise Factors" on the Differences between Predictions of %Body Fat from "Stature^2/Resistance plus Anthropometry" and from Underwater Weighing in Men.

Source of Covariance	df	F-value	P-value
Exercise group	2	1.30	0.278
Interval from last meal	1	1.39	0.242
Interval from last drink	1	0.33	0.570
Test for parallelism			
Interval from last meal by exercise group	2	0.16	0.851
Interval from last drink by exercise group	2	0.27	0.764
Test for nonadditive effect			
Interval from last meal by Interval from last drink	1	0.23	0.634

TABLE E-3. Analysis of Covariance Tests for the Influence of "Physiological Noise Factors" on the Differences between Predictions of Total Body Fat from "Stature^2/Resistance plus Anthropometry" and from Underwater Weighing in Men.

Source of Covariance	df	F-value	P-value
Exercise group	2	1.72	0.185
Interval from last meal	1	2.09	0.152
Interval from last drink	1	0.37	0.546
Test for parallelism			
Interval from last meal by exercise group	2	0.22	0.800
Interval from last drink by exercise group	2	0.18	0.838
Test for nonadditive effect			
Interval from last meal by Interval from last drink	1	0.01	0.977

TABLE E-4. Analysis of Covariance Tests for the Influence of "Physiological Noise Factors" on the Differences between Predictions of Fat Free Mass from "Stature^2/Resistance plus Anthropometry" and from Underwater Weighing in Men.

Source of Covariance	df	F-value	P-value
Exercise group	2	1.72	0.185
Interval from last meal	1	2.09	0.152
Interval from last drink	1	0.37	0.546
Test for parallelism			
Interval from last meal by exercise group	2	0.22	0.800
Interval from last drink by exercise group	2	0.18	0.838
Test for nonadditive effect			
Interval from last meal by Interval from last drink	1	0.01	0.977

TABLE E-5. Analysis of Covariance Tests for the Influence of Physiological Noise Factors" on the Differences between Predictions of Body Density from "Stature^2/Resistance plus Anthropometry" and from Underwater Weighing in Women.

Source of Covariance	df	F-value	P-value
Exercise group	2	5.84	0.004*
Interval from last meal	1	2.79	0.099
Interval from last drink	1	0.05	0.825
Test for parallelism			
Interval from last meal by exercise group	2	0.11	0.897
Interval from last drink by exercise group	2	0.31	0.736
Test for nonadditive effect			
Interval from last meal by Interval from last drink	1	0.16	0.691

*$0.01 \leq P \leq 0.05$

TABLE E-6. Analysis of Covariance Tests for the Influence of Physiological Noise Factors" on the Differences between Predictions of %Body Fat from "Stature^2/ Resistance plus Anthropometry" and from Underwater Weighing in Women.

Source of Covariance	df	F-value	P-value
Exercise group	2	5.74	0.005*
Interval from last meal	1	2.75	0.102
Interval from last drink	1	0.03	0.859
Test for parallelism			
Interval from last meal by exercise group	2	0.13	0.877
Interval from last drink by exercise group	2	0.33	0.718
Test for nonadditive effect			
Interval from last meal by Interval from last drink	1	0.16	0.690

*$0.01 \leq P \leq 0.05$

TABLE E-7. Analysis of Covariance Tests for the Influence of "Physiological Noise Factors" on the Differences between Predictions of Total Body Fat from "Stature^2/Resistance plus Anthropometry" and from Underwater Weighing in Women.

Source of Covariance	df	F-value	P-value
Exercise group	2	5.08	0.009*
Interval from last meal	1	2.64	0.108
Interval from last drink	1	0.03	0.871
Test for parallelism			
Interval from last meal by exercise group	2	0.53	0.590
Interval from last drink by exercise group	2	0.49	0.618
Test for nonadditive effect			
Interval from last meal by Interval from last drink	1	0.14	0.713

*$0.01 \leq P \leq 0.05$

TABLE E-8. Analysis of Covariance Tests for the Influence of "Physiological Noise Factors" on the Differences between Predictions of Fat Free Mass from "Stature^2/Resistance plus Anthropometry" and from Underwater Weighing in Women.

Source of Covariance	df	F-value	P-value
Exercise group	2	5.08	0.009*
Interval from last meal	1	2.64	0.108
Interval from last drink	1	0.03	0.871
Test for parallelism			
Interval from last meal by exercise group	2	0.53	0.590
Interval from last drink by exercise group	2	0.49	0.618
Test for nonadditive effect			
Interval from last meal by Interval from last drink	1	0.14	0.713

*$0.01 \leq P \leq 0.05$

APPENDIX F

STATISTICAL METHODS

Normality of Distributions

The statistical analyses were designed to investigate the reliability of the instruments and observers, the validity of bioelectric impedance and the EchoScan 1502 ultrasound machines, and to estimate the effects of physiological factors that could affect these measurements. The normality of the variables was considered first because many of the statistical tests are based upon the assumption that the variables are normally distributed.

The Kolmogorov-Smirnov test was used to examine the distributions of the data in the present study. The test involves specifying the cumulative distribution function that would occur under the normal distribution and comparing this with the observed cumulative distribution function. Let $x_{(1)}, x_{(2)} \cdots, x_{(n)}$ be the order statistic of $x_1, x_1 \cdots, x_n$. Define

$$Z_{(i)} = \frac{x_{(i)} - x}{S}$$

where $\bar{x}$, S are the mean and standard deviation of the x_i, $i = 1, 2, \cdots, n$. The cumulative probability of the standard normal distribution is

$$F_0(x_{(i)}) = \Phi\left\{\frac{x_{(i)} - x}{S}\right\}$$

Define
$$D_n^* = \underset{i}{\mathrm{Max}}\left\{\mathrm{Max}\left[F_0(x_{(i)}) - \frac{i-1}{n}, \frac{i}{n} - F_0(x_{(i)})\right]\right\}$$

If $D_n^* > K_\alpha$ then the null hypothesis is rejected, where $K_\alpha = \dfrac{C\alpha}{\sqrt{n} - 0.01 + \frac{0.85}{\sqrt{n}}}$

The results of the Kolmogorov-Smirnov test are presented in Tables F-1 to F-4, in which C_α was determined from Stephen's data (176). Two of the distributions of the inter-machine and intra-machine differences combined were normally distributed in the men before logarithmic transformation, but most of the distributions of the combined differences for women were normal before logarithmic transformation. After logarithmic transformations, all these distributions were normal except one in men and three in women (Table F-1). Using the means for all observations within individuals in the total sample, the distributions for resistance were normal. Most of the distributions of the ultrasonic measurements of subcutaneous adipose tissue were normally distributed before logarithmic transformation, and all were normally distributed after logarithmic transformation (Table F-2). Corresponding analyses for skinfolds showed that none of the distributions were normal for men before logarithmic transformation, but those for three of the seven sites were normal for women before transformation. After logarithmic transformation, the distributions of skinfold thicknesses were normal at all sites for the women and most sites for the men (Table F-3).

Kolmogorov-Smirnov tests showed the distributions of BD, %BF, and TBF were non-normal in men but all except BD became normal after logarithmic transformation (Table F-4). The corresponding distributions were normal for the women without logarithmic transformation.

Reliability

Instrument and observer reliability was analyzed by comparing inter-machine and intra-machine, inter-observer and intra-observer differences. Distribution statistics including mean, SD, standard error of the mean, and selected percentiles were calculated for these absolute differences. The TE, the CV, and the CR were computed also.

The TE was defined as $$TE = \sqrt{\frac{\sum d_i^2}{2N}}$$

where d_i = the paired difference between (within) the observers (machines) of the i^{th} participant, N = the number of participants. The CV was

$$CV = \frac{TE}{\overline{X}}$$

where X is the overall mean of observations.

The CR ρ is the intra-class correlation coefficient of a random effects model (177),

$$Y_{ij} = \mu + A_i + \varepsilon_{ij}$$

where Y_{ij} is the j^{th} measurement of i^{th} participant, μ is the mean of the general population, A_i is the i^{th} participant's effects, and ε_{ij} is the error of j^{th} measurement of the i^{th} participant. A_i and ε_{ij} are normally distributed with zero means and variances $\sigma_A{}^2$, σ^2 respectively.

The calculation of ρ was obtained from a nested analysis of variance with the effects of the observers (machines) nested within the participant (170).

$$\rho = \frac{\sigma_A^2}{\sigma_A^2 + \sigma^2}$$

An analysis of variance, using a three-factor factorial mixed effects model, was performed also to test the main effects and interaction effects of machines and observers (178).

TABLE F-1. D Statistics of Kolmogorov-Smirnov Tests of Normality for Inter- and Intra-machine Differences Combined.

	Men		Women	
Variables	Before Tran.	After Tran.[a]	Before Tran.	After Tran.[a]
Resistance	0.238*	0.223	0.261*	0.270*
Ultrasound				
Triceps	0.117*	0.078	0.107*	0.113*
Subscapular	0.126*	0.067	0.948	0.971
Biceps	0.110*	0.067	0.106	0.064
Midaxillary	0.122*	0.069	0.145*	0.101
Paraumbilical	0.178*	0.126*	0.135	0.099
Anterior Thigh	0.103	0.102	0.090	0.106
Lateral Calf	0.191*	0.132	0.090	0.087
Breast	0.117*	0.704	0.113	0.121*
Buttocks	0.091	0.107	0.083	0.078

* $P < 0.01$
a. Tran. = logarithmic transformation

TABLE F-2. D Statistics of Kolmogorov-Smirnov Tests of Normality for Resistance and Ultrasound Variables in the Total Sample.

	Men		Women	
Variables	Before Tran.	After Tran.[a]	Before Tran.	After Tran.[a]
Resistance	0.074	0.067	0.053	0.057
Ultrasound				
Triceps	0.086	0.048	0.088	0.053
Subscapular	0.098	0.089	0.075	0.056
Biceps	0.132*	0.089	0.123*	0.056
Midaxillary	0.145*	0.090	0.135*	0.086
Paraumbilical	0.095	0.094	0.084	0.113
Anterior Thigh	0.068	0.064	0.096	0.083
Lateral Calf	0.099	0.068	0.135*	0.082

* $P < 0.01$
a. Tran. = logarithmic transformation

TABLE F-3. D Statistics of Kolmogorov-Smirnov Tests of Normality for Skinfold Caliper Measurements in the Total Sample.

Variables	Men		Women	
	Before Tran.	After Tran.[a]	Before Tran.	After Tran.[a]
Triceps	0.135*	0.061	0.102	0.060
Subscapular	0.192*	0.139*	0.162*	0.097
Biceps	0.228*	0.184*	0.132*	0.084
Midaxillary	0.188*	0.112*	0.200*	0.109
Paraumbilical	0.179*	0.103	0.113	0.055
Anterior Thigh	0.164*	0.079	0.100	0.066
Lateral Calf	0.147*	0.066	0.118	0.060

* $P < 0.01$

a. Tran. = logarithmic transformation

TABLE F-4. D Statistics for Kolmogorov-Smirnov Tests of Normality for Body Composition Variables from Underwater Weighing.

Variables	Men		Women	
	Before Tran.	After Tran.[a]	Before Tran.	After Tran.[a]
Body Density	0.129*	0.132*	0.085	0.088
Percent Body Fat	0.135*	0.073	0.090	0.040
Total Body Fat	0.149*	0.064	0.110	0.081
Fat Free Mass	0.043	0.047	0.076	0.055

* $P < 0.01$

a. Tran. = logarithmic transformation

Validity

Tests of validity employed three types of analytic models: regression, correlation analyses, and "t" tests. The equations for predicting body composition from stature^2/resistance used a maximum R^2 improvement method (14) to select the best equation.

The criteria for evaluating these equations were as follows:

(1) $C(p) \leq p$

(2) Where C(p), as described by Mallows (179) is an estimate of the standardized total mean squared errors of prediction,

$$C(p) = \frac{(SSE)_p}{\sigma^2} + 2p - N$$

in which (SSE)p is the sum of squared errors of prediction in a p-term equation, while σ^2 is obtained from the model with a full set of predictor variables. A stepwise regression method was applied also to the observed data. If the models selected by the maximum R^2 improvement method differ from those selected by the stepwise procedures, it may imply that the former have many regressors with no explanation capability and C(p) becomes unreliable since σ^2 is large. A detailed discussion is given by Chatterjee and Price (180).

For every selected model, the RMSE, multiple R^2 and value for the partial F statistic of the predictor variable, and adjusted R^2 were reported. RMSE is a measure of the goodness of prediction. Let Y_i be the observed value of the i^{th} participant, $\hat{Y}_i$ be the predicted value of Y_i obtained from the model, p be the number of predictor variables in the fitted equation, and N be the number of participants, then RMSE is

$$\frac{\Sigma (Y_i - \hat{Y}_i)^2}{N - p - 1}$$

The multiple R^2 value is the proportion of the total variation that is explained by the regression equation, algebraically, where $Y = \sum Y_i/N$. The adjusted R^2

$$R^2 = \frac{\sum(Y_i - \hat{Y}_i)^2}{\sum(Y_i - \bar{Y})^2}$$

is the multiple R^2 adjusting for the degree of freedom due to the sum of square of errors.

$$R^2_{adj} = 1 - \frac{(N-1)(1-R^2)}{N-p-1}$$

Multicollinearity among the regressors for each selected model was examined. The variance inflation factor (VIF) indicated the extent of multicollinearity. When VIF is equal to 1, there is no multicollinearity. VIF is the reciprocal of $1-R^2$, where R^2 is obtained by regressing the regressor of interest on the other regressors.

Hypotheses related to the validity of the EchoScan 1502 ultrasound machine were tested by correlating and regressing skinfold caliper measurements on corresponding ultrasonic measurements. Multiple regressions of the differences between skinfold caliper measurements and corresponding ultrasonic measurements on other variables were performed by a stepwise procedure with 0.10 as the criterion for entry into the equation.

A t-test was employed to evaluate whether the differences between the estimates of BD from impedance plus anthropometry and from underwater weighing were the same between blacks and whites. It was assumed that the differences for blacks and for whites were independent random samples from two normally distributed populations. The equality of variances based on F statistic was tested. If the test results were nonsignificant at $\alpha = 0.05$, then the t statistic and its degrees of freedom were modified.

Physiological Factors

Tests for the possible effects of physiological factors on ultrasonic and bioelectric resistance measurements employed simple linear regression, time series, and analysis of covariance. A simple linear regression was performed to determine if resistance values were significantly related to their time of measurements.

Analysis of covariance is designed to study the group differences while adjusting for the covariates. The model of one covariate and one-way classification is illustrated without loss of generality.

$$Y_{ij} = \mu + \alpha_i + \beta_{ij} + \varepsilon_{ij}$$

where Y_{ij} is the response variable, μ is overall mean of the response variable, α_i is the i^{th} group effect, β is the regression coefficient of the covariate x_{ij}, and ε_{ij} is the error. The assumptions of the model are linearity between response variable and covariate, parallel slopes among groups in the relationship of response variable and covariate, and homogeneity of variance. A test of the hypothesis on the covariate effects can be performed by calculating the partial F statistic adjusting for the group effects. Equality of the adjusted group means is tested based on the partial F statistic adjusting for the covariate.

Cross-sectional resistance data were evaluated in relation to the possible effects of contraceptive usage and the possible effects of time interval from the date of examination to the first day of the last menstrual period. In the model, resistance was the response variable, contraceptive usage was the categorial variable with the time interval as the covariate.

Time trend models are appropriate for determining a pattern across time. They can be fitted to data using regression analysis. The linear trend model is expressed as:

$$Y_t = a + b_t + \varepsilon_t ,$$

where Y_t = the observed value at time t, a is the estimated value at time zero, b is the scope and ε_t is the error at time t. The quadratic model,

$$Y_t = a + b_1 t + b_2 t^2 + \varepsilon_t$$

is an extension of the linear trend model to a curvelinear model.

A test for autocorrelation of the residuals was performed, assuming that the errors constituted a first order autoregressive series, using the Durbin-Watson statistic d,

$$d = \frac{\sum_{t=2}^{N} (\varepsilon_t - \varepsilon_{t-1})^2}{\sum_{t=2}^{N} \varepsilon_t^2}$$

The autocorrelations were removed by the method of Cochrane and Orcutt (181).

APPENDIX G

VARIATION WITH MENSTRUAL CYCLE

TABLE G-1. Distribution Statistics for Anthropometric Variables at the First and Last Examinations of Women Taking Oral Contraceptives (N = 11).

Variables	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
First Examination						
weight (kg)	63.37	12.86	3.88	48.5	58.1	89.0
stature (cm)	166.55	5.93	1.79	157.5	166.1	179.2
calf circumference (cm)	36.19	3.52	1.06	32.3	35.3	45.3
arm circumference (cm)	28.48	4.42	1.33	24.5	26.0	38.1
Last Examination						
weight (kg)	63.44	12.73	3.84	48.4	58.3	85.0
stature (cm)	166.58	5.88	1.77	157.8	166.6	179.6
calf circumference (cm)	36.17	3.29	0.99	32.7	34.6	43.9
arm circumference (cm)	28.40	4.33	1.31	23.3	26.6	37.3

TABLE G-2. Distribution Statistics for Anthropometric Variables at the First and Last Examinations of Women Not Taking Oral Contraceptives (N = 18).

Variables	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
First Examination						
weight (kg)	65.86	17.68	4.17	49.8	57.9	116.2
stature (cm)	163.23	7.80	1.84	149.0	163.9	175.7
calf circumference (cm)	36.82	5.78	1.36	29.3	35.2	52.2
arm circumference (cm)	29.65	4.90	1.15	24.1	28.9	43.4
Last Examination						
weight (kg)	65.78	18.05	4.25	49.9	57.9	117.3
stature (cm)	163.19	7.86	1.85	148.9	163.7	176.2
calf circumference (cm)	36.71	5.93	1.40	29.2	34.7	52.4
arm circumference (cm)	29.69	5.10	1.20	23.9	28.7	44.3

TABLE G-3. Distribution Statistics for Stature^2/Resistance (cm^2/ohm) for Each Woman Taking Oral Contraceptives (N = 34-35 days).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
4	54.26	2.16	0.37	48.11	54.44	58.94
5	58.79	1.66	0.28	55.05	58.57	61.63
6	48.36	1.21	0.21	46.36	48.23	50.72
7	45.62	1.17	0.20	43.76	45.30	49.56
8	47.64	0.99	0.17	45.14	47.83	49.09
9	46.07	1.86	0.31	43.39	45.94	55.28
10	38.56	0.87	0.15	36.61	38.45	40.30
13	51.22	2.17	0.37	45.33	51.16	55.60
22	46.36	1.45	0.24	42.06	46.56	49.35
26	51.23	1.37	0.23	48.93	51.10	54.32
29	45.38	1.38	0.23	42.84	45.26	48.06

TABLE G-4. Distribution Statistics for Daily Increments of Stature^2/ Resistance (cm^2/ohm per day) for Each Woman Taking Oral Contraceptives (N = 32-34 days).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
4	0.01	2.49	0.43	-4.88	-0.05	4.60
5	0.17	1.98	0.34	-6.45	0.49	3.42
6	-0.02	1.12	0.19	-2.32	0.08	2.09
7	-0.11	1.51	0.26	-3.87	-0.03	2.68
8	-0.03	1.28	0.22	-1.86	-0.25	2.12
9	-0.03	2.51	0.43	-8.76	-0.04	9.34
10	0.002	1.06	0.19	-1.98	0.14	2.22
13	0.003	2.84	0.49	-6.33	-0.44	6.13
22	0.07	1.77	0.30	-4.72	0.14	5.24
26	0.11	1.60	0.28	-3.53	0.33	3.30
29	-0.09	1.32	0.22	-2.12	0.08	3.48

TABLE G-5. Minimum and Maximum Values for $Stature^2/Resistance$ (cm^2/ohm) Within the Serial Data for Each Woman Taking Oral Contraceptives with the Days of the Menstrual Cycles at Which These Values Were Noted.

Woman No.	Minimum	Corresponding Day	Maximum	Corresponding Day
4	48.11	8	58.94	25
5	55.05	4	61.63	22
6	46.36	8	50.72	4
7	43.76	1	49.56	22
8	45.14	11	49.09	18
9	43.39	19	55.28	8
10	36.61	5	40.30	17
13	45.33	12	55.60	0
22	42.06	12	49.35	4
26	48.93	10	54.32	23
29	42.84	4	48.06	25

TABLE G-6. Distribution Statistics for Weight (kg) of Each Woman Taking Oral Contraceptives (N = 35 days).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
4	88.38	1.20	0.20	85.5	88.5	90.9
5	70.13	0.70	0.12	68.7	70.1	71.5
6	55.84	0.40	0.07	55.1	55.9	56.7
7	65.41	0.35	0.06	64.5	65.4	66.3
8	55.93	0.53	0.09	54.9	56.0	56.9
9	58.27	0.46	0.08	57.2	58.3	59.6
10	52.14	0.44	0.07	51.3	52.2	53.2
13	78.38	0.99	0.17	76.8	78.3	80.7
22	53.06	0.56	0.09	51.9	53.1	54.2
26	77.38	0.55	0.09	76.4	77.3	78.7
29	49.17	0.41	0.07	48.0	49.1	49.9

TABLE G-7. Distribution Statistics for Daily Increments of Weight (kg/day) for Each Woman Taking Oral Contraceptives (N = 34 days).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
4	-0.10	0.76	0.13	-1.5	-0.1	1.5
5	0.32	0.72	0.12	-1.2	-0.1	1.8
6	-0.04	0.47	0.08	-1.3	0.0	0.8
7	0.02	0.37	0.06	-0.8	0.1	0.7
8	0.02	0.58	0.10	-1.3	0.0	1.3
9	0.01	0.47	0.08	-0.7	0.0	0.9
10	0.02	0.47	0.08	-1.2	0.0	0.9
13	0.06	0.90	0.15	-1.9	0.2	2.1
22	-0.15	0.45	0.08	-1.2	0.0	0.8
26	0.11	0.63	0.11	-1.2	0.0	1.3
29	0.003	0.50	0.09	-0.9	0.0	1.3

TABLE G-8. Distribution Statistics for Estimated Percent Body Fat (BF%)* of Each Woman Taking Oral Contraceptives (N = 34-35 days).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
4	49.29	1.61	0.27	45.42	49.19	53.49
5	49.75	1.25	0.21	47.60	49.76	53.97
6	21.42	0.98	0.17	19.51	21.66	23.00
7	27.47	0.95	0.16	24.10	27.73	29.01
8	20.79	0.77	0.13	19.51	20.65	22.60
9	22.65	1.55	0.26	14.89	22.74	24.75
10	26.95	0.67	0.12	25.85	26.98	28.52
13	37.35	1.63	0.28	33.94	37.38	42.15
22	20.91	1.10	0.19	18.72	20.70	24.33
26	35.19	1.11	0.19	32.58	35.27	37.17
29	24.07	1.11	0.19	22.05	24.20	26.04

* %BF predicted from equation in Table C-6.

TABLE G-9. Distribution Statistics for Daily Increments of Estimated Values for Percent Body Fat (BF%)* of Each Woman Taking Oral Contraceptives (N = 32-34 days).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
4	-0.04	1.92	0.33	-3.72	0.01	3.57
5	-0.13	1.53	0.26	-2.61	-0.24	5.16
6	0.01	0.87	0.15	-1.60	-0.05	1.64
7	0.10	1.22	0.21	-2.16	0.05	3.43
8	0.03	0.99	0.17	-1.74	0.11	1.61
9	0.03	2.08	0.36	-7.72	0.04	7.34
10	0.00	0.86	0.15	-1.94	-0.05	1.65
13	0.02	2.19	0.38	-4.61	0.17	5.35
22	-0.07	1.40	0.24	-4.22	-0.13	3.76
26	-0.07	0.24	0.24	-2.80	-0.18	2.86
29	0.08	1.05	0.18	-2.85	-0.10	1.70

* %BF predicted from equation in Table C-6.

TABLE G-10. Linear Regression of Stature^2/Resistance (cm^2/ohm) Versus Days from Last Menstrual Period for Each Woman Taking Oral Contraceptives.

Woman No.	Independent Variable	Regression Coefficients	t**	P Value	Durbin-Watson d Statistics
No Significant Autocorrelations					
4	constant term	53.21*	68.45	0.0001	1.25
	days	0.08	1.57	0.128	
5	constant term	58.78*	92.71	0.0001	1.33
	days	0.01	0.35	0.732	
7	constant term	45.34*	121.72	0.0001	2.02
	days	0.01	0.44	0.662	
9	constant term	46.45*	62.60	0.0001	1.78
	days	-0.03	-0.67	0.512	
10	constant term	37.89*	111.76	0.0001	1.51
	days	0.05	2.03	0.054	
13	constant term	52.67*	63.08	0.0001	1.70
	days	-0.11	-1.56	0.136	
22	constant term	45.22*	84.46	0.0001	1.93
	days	0.08	2.06	0.051	
26	constant term	50.43*	104.17	0.0001	1.68
	days	0.08*	2.44	0.023	
29	constant term	43.60*	123.43	0.0001	2.06
	days	0.14*	6.16	0.0001	
Third Order Significant					
8	constant term	47.62*	185.53	0.0001	ρ_3 = 0.438*
	days	-0.009	-0.54	0.595	
First and Third Order Significant					
6	constant term	48.21*	86.78	0.0001	ρ_1 = -0.772*
	days	0.007	0.21	0.835	ρ_3 = 0.397*

* significant at $\alpha = 0.05$
** statistics for Ho: coefficient = 0

TABLE G-11. Non-Linear Regressions of $Stature^2/Resistance$ (cm^2/ohm) Versus Days and $Days^2$ from Last Menstrual Periods for Each Woman Taking Oral Contraceptives.

Woman No.	Independent Variable	Regression Coefficients	t**	P Value	Durbin-Watson d Statistics
No Significant Autocorrelations					
4	constant term	54.51*	50.49	0.0001	1.38
	days	-0.22	-1.20	0.2407	
	$days^2$	0.01	1.68	0.1058	
5	constant term	60.08*	70.28	0.0001	1.55
	days	-0.29	-1.96	0.0618	
	$days^2$	0.01*	2.12	0.0439	
7	constant term	44.73*	86.37	0.0001	2.24
	days	0.15	1.72	0.0970	
	$days^2$	-0.005	-1.66	0.1088	
9	constant term	46.40*	42.66	0.0001	1.78
	days	-0.02	-0.11	0.9142	
	$days^2$	-0.0004	-0.06	0.9514	
10	constant term	38.33*	50.13	0.0001	1.52
	days	-0.07	-0.19	0.8581	
	$days^2$	0.002	0.05	0.9640	
13	constant term	54.13*	48.24	0.0001	1.96
	days	-0.54*	-2.19	0.0409	
	$days^2$	0.02	1.83	0.0832	
22	constant term	46.05*	61.97	0.0001	2.12
	days	-0.14	-0.95	0.3536	
	$days^2$	0.009	1.55	0.1353	
29	constant term	43.57*	84.21	0.0001	2.06
	days	0.14	1.64	0.1139	
	$days^2$	-0.0003	-0.08	0.9346	
First Order Significant					
26	constant term	51.98*	141.02	0.0001	0.43*
	days	-0.32*	-4.47	0.0002	
	$days^2$	0.02*	5.83	0.0001	
Third Order Significant					
8	constant term	48.10*	128.54	0.0001	ρ_3 = 0.49*
	days	-0.11	-1.77	0.0892	
	$days^2$	0.004	1.69	0.1048	
First and Third Order Significant					
6	constant term	49.29*	78.94	0.0001	ρ_1 = -0.58*
	days	-0.22	-2.05	0.0519	ρ_3 = 0.41*
	$days^2$	0.008*	2.15	0.0427	

* significant at α = 0.05
** statistics for Ho: coefficient = 0

TABLE G-12. Distribution Statistics for $Stature^2/Resistance$ (cm^2/ohm) for Each Woman not Taking Oral Contraceptives (N = 34-35 days).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
2	43.50	1.48	0.25	40.75	43.48	46.67
3	46.89	1.30	0.22	43.22	47.13	50.10
11	47.24	1.48	0.25	41.85	47.06	50.64
16	44.26	1.35	0.23	40.98	44.29	46.78
17	43.40	1.46	0.25	40.15	43.57	46.00
18	39.94	0.97	0.17	37.61	39.95	42.13
19	48.33	1.16	0.20	45.73	48.32	51.13
20	44.01	1.04	0.18	41.45	44.02	46.47
21	64.82	2.25	0.38	61.03	64.73	69.06
23	57.06	1.95	0.33	53.21	57.09	61.45
24	46.84	1.07	0.18	45.21	46.71	48.95
25	47.50	1.17	0.20	45.44	47.40	50.14
27	50.46	1.73	0.29	47.21	49.97	54.29
28	44.90	1.48	0.25	41.96	44.75	48.38
30	45.85	1.69	0.29	41.82	45.62	49.46
31	38.42	1.16	0.19	34.34	38.41	40.84
32	52.19	2.78	0.47	48.11	52.13	65.38
33	30.84	0.95	0.16	29.09	30.99	33.78

TABLE G-13. Minimum and Maximum Values for Stature^2/Resistance (cm^2/ohm) Within the Serial Data for Each Woman Not Taking Oral Contraceptives with the Days of the Menstrual Cycles on Which They Occurred.

Woman No.	Minimum	Corresponding Day	Maximum	Corresponding Day
2	40.75	26	46.67	13
3	43.22	19	50.10	2
11	41.85	15	50.64	32
16	40.98	15	46.78	2
17	40.15	32	46.00	21
18	37.61	4	42.13	9
19	45.73	16	51.13	1
20	41.45	32	46.47	22
21	61.03	1	69.06	22
23	53.21	10	61.45	19
24	45.21	3	48.95	16
25	45.44	20	50.14	21
27	47.21	25	54.29	2
28	41.96	0	48.38	6
30	41.82	21	49.46	28
31	34.34	9	40.84	31
32	48.11	15	65.38	8
33	29.09	5	33.78	18

TABLE G-14. Distribution Statistics for Daily Increments of Stature^2/ Resistance (cm^2/ohm per day) for Each Woman not Taking Oral Contraceptives (N = 32-34 days).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
2	-0.04	1.41	0.24	-3.33	-0.03	3.38
3	0.08	1.69	0.29	-3.99	0.23	3.21
11	-0.10	1.51	0.27	-4.28	-0.16	4.67
16	-0.08	1.53	0.26	-2.86	-0.30	3.33
17	0	1.98	0.34	-4.73	0.26	4.65
18	0.03	1.06	0.19	-2.30	-0.03	2.16
19	0.05	1.06	0.18	-2.43	0.08	1.64
20	-0.07	1.44	0.25	-2.23	-0.21	3.14
21	-0.02	2.33	0.40	-3.97	-0.42	3.84
23	0.03	2.09	0.36	-5.22	0.37	4.49
24	0	1.39	0.24	-2.89	0.08	2.38
25	-0.11	1.41	0.25	-3.85	-0.27	3.21
27	-0.07	2.06	0.35	-6.04	-0.23	4.61
28	0.03	1.88	0.32	-4.73	-0.12	4.52
30	0.04	1.87	0.32	-5.10	0.19	2.81
31	-0.03	1.44	0.25	-4.08	-0.03	4.72
32	-0.09	3.67	0.63	-14.21	-0.31	12.81
33	0.01	0.87	0.15	-1.71	0.04	2.21

TABLE G-15. Distribution Statistics for Weight (kg) of Each Woman not Taking Oral Contraceptives (N = 35 days).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
2	72.22	0.52	0.09	71.4	72.3	73.2
3	79.31	0.63	0.11	78.0	79.4	80.5
11	66.43	0.99	0.17	65.1	66.5	68.2
16	68.42	0.82	0.14	66.5	68.5	69.6
17	58.37	0.75	0.13	56.8	58.3	59.8
18	50.21	0.41	0.07	48.8	50.2	50.9
19	56.98	0.59	0.09	55.7	57.0	58.1
20	51.90	0.44	0.07	50.5	52.0	52.5
21	117.97	1.38	0.23	115.3	117.8	121.1
23	99.43	0.63	0.11	97.7	99.4	100.8
24	78.78	0.48	0.08	78.0	78.8	80.1
25	53.15	0.86	0.14	51.6	53.1	54.8
27	55.97	0.62	0.10	54.8	55.8	57.2
28	56.02	0.49	0.08	55.2	55.9	57.1
30	54.85	0.27	0.04	54.3	54.9	55.3
31	61.17	0.44	0.07	60.4	61.1	62.2
32	58.57	0.75	0.13	57.1	58.4	59.9
33	52.20	0.29	0.05	51.6	52.2	52.8

TABLE G-16. Distribution Statistics for Daily Increments of Weight (kg/day) of Each Woman not Taking Oral Contraceptives (N = 34 increments).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
2	0.01	0.41	0.07	-0.6	0.0	1.2
3	0.04	0.45	0.08	-1.0	0.0	0.9
11	0.08	0.62	0.11	-0.9	0.1	1.8
16	-0.08	0.51	0.09	-1.0	-0.1	1.0
17	0.06	0.76	0.13	-1.3	0.3	1.5
18	0.02	0.56	0.09	-1.4	-0.1	1.4
19	0.04	0.53	0.09	-1.2	0.1	1.1
20	-0.01	0.52	0.09	-1.1	0.1	1.5
21	0.02	0.75	0.13	-1.6	0.1	2.0
23	0.01	0.59	0.10	-0.9	0.1	1.1
24	-0.02	0.54	0.09	-1.0	0	1.5
25	0.0	0.57	0.09	-1.1	-0.1	1.0
27	-0.02	0.75	0.13	-1.6	-0.2	1.6
28	-0.04	0.52	0.09	-1.1	-0.2	0.9
30	-0.003	0.37	0.06	-0.7	-0.1	0.8
31	-0.04	0.48	0.08	-1.0	0.0	1.3
32	-0.07	0.44	0.07	-0.9	-0.1	0.9
33	0.01	0.30	0.05	-0.6	0.0	0.5

TABLE G-17. Distribution Statistics for Estimated Percent Body Fat (%BF)* of Each Woman not Taking Oral Contraceptives (N = 34-35 days).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
2	39.21	1.13	0.19	36.89	39.17	41.42
3	46.40	0.98	0.17	44.12	46.29	49.25
11	30.93	1.12	0.19	28.61	30.88	35.18
16	35.98	1.00	0.17	34.23	35.98	38.28
17	29.30	1.12	0.19	27.43	29.24	31.81
18	24.20	0.77	0.13	22.60	24.18	27.25
19	21.92	0.85	0.14	19.76	21.87	23.99
20	23.74	0.82	0.14	21.74	23.59	25.42
21	63.75	1.64	0.28	60.50	63.78	67.16
23	56.34	1.51	0.25	53.14	56.30	59.50
24	45.50	0.86	0.15	43.67	45.48	47.99
25	22.82	0.92	0.16	20.86	22.92	24.27
27	18.65	1.28	0.22	15.70	19.00	20.98
28	27.38	1.19	0.20	24.62	27.60	29.66
30	30.24	1.38	0.23	27.29	30.44	33.60
31	38.26	0.94	0.16	36.41	38.21	41.53
32	17.64	2.23	0.38	6.57	17.90	20.59
33	29.71	0.75	0.13	27.36	29.61	31.06

* %BF predicted from the equation in Table C-6.

TABLE G-18. Distribution Statistics for Daily Increments of Estimated Percent Body Fat (%BF)* of Each Woman not Taking Oral Contraceptives (N = 32-34 days).

Woman No.	Mean	SD	SE of Mean	Minimum Value	Median	Maximum Value
2	0.04	1.10	0.19	-2.67	0.04	2.57
3	-0.05	1.39	0.24	-2.69	-0.13	3.19
11	0.09	1.25	0.22	-3.90	0.03	3.71
16	0.04	1.24	0.21	-2.48	0.33	2.40
17	0.02	1.56	0.27	-3.61	-0.19	3.86
18	-0.03	0.84	0.15	-1.98	0.13	2.10
19	-0.03	0.78	0.13	-1.28	-0.03	1.86
20	0.06	1.16	0.20	-2.13	0.16	1.82
21	0.02	1.81	0.31	-3.03	0.09	3.33
23	-0.02	1.67	0.29	-3.60	-0.15	4.08
24	-0.01	1.09	0.19	-1.95	-0.09	2.25
25	0.10	1.15	0.20	-2.35	0.27	3.16
27	0.05	1.57	0.27	-3.38	0.12	4.51
28	-0.04	1.48	0.25	-3.59	0.19	3.80
30	-0.03	1.51	0.26	-2.46	-0.23	4.01
31	0.02	1.19	0.20	-3.89	-0.05	3.32
32	0.06	3.05	0.52	-10.82	0.87	11.73
33	-0.01	0.74	0.13	-1.93	-0.00	1.32

* %BF predicted from the equation in Table C-6.

TABLE G-19. Regressions of Stature^2/Resistance (cm^2/ohm) Versus Days from Last Menstrual Period for Each Woman not Taking Oral Contraceptives.

Woman No.	Independent Variable	Regression Coefficients	t**	P Value	Durbin-Watson d Statistics
No Significant Autocorrelations					
3	constant term	47.13*	106.78	0.0001	1.775
	days	-0.009	-0.38	0.705	
11	constant term	46.22*	102.47	0.0001	1.213
	days	0.06*	2.66	0.012	
17	constant term	44.01*	88.01	0.0001	1.664
	days	-0.04	-1.45	0.157	
18	constant term	40.53*	115.43	0.0001	1.298
	days	-0.04	-1.89	0.070	
19	constant term	49.29*	121.47	0.0001	1.014
	days	-0.06*	-2.28	0.031	
24	constant term	46.39*	121.82	0.0001	1.738
	days	0.02	1.33	0.194	
25	constant term	47.81*	119.15	0.0001	1.571
	days	-0.03	-1.12	0.274	
28	constant term	44.77*	74.96	0.0001	1.518
	days	0.01	0.35	0.729	
30	constant term	46.39*	82.33	0.0001	1.261
	days	-0.02	-0.66	0.514	
31	constant term	37.74*	98.94	0.0001	1.688
	days	0.04	1.97	0.058	
32	constant term	53.66*	35.70	0.0001	1.971
	days	-0.18	-1.28	0.217	
First Order Significant					
2	constant term	43.28*	46.39	0.0001	ρ_1 = -0.477*
	days	0.005	0.09	0.933	
33	constant term	30.34*	55.89	0.0001	ρ_1 = -0.555*
	days	0.03	1.06	0.297	
Second Order Significant					
16	constant term	44.07*	67.43	0.0001	ρ_2 = -0.370*
	days	0.007	0.19	0.846	
20	constant term	44.02*	163.82	0.0001	ρ_2 = -0.365*
	days	-0.0005	-0.04	0.968	

TABLE G-19. Regressions of Stature^2/Resistance (cm^2/ohm) Versus Days from Last Menstrual Period for Each Women not Taking Oral Contraceptives. (Continued)

Woman No.	Independent Variable	Regression Coefficients	t**	P Value	Durbin-Watson d Statistics
Third Order Significant					
21	constant term	62.68*	132.09	0.0001	ρ_3 = 0.400*
	days	0.18*	5.98	0.0001	
23	constant term	56.05*	114.66	0.0001	ρ_3 = 0.474*
	days	0.09*	2.74	0.001	
Fourth Order Significant					
27	constant term	50.77*	122.79	0.0001	ρ_4 = 0.386*
	days	-0.03	-1.16	0.254	

* significant at α = 0.05

** statistics for Ho: coefficient = 0

TABLE G-20. Regressions of Stature^2/Resistance (cm^2/ohm) Versus Days and Days^2 from the Last Menstrual Periods for Each Woman not Taking Oral Contraceptives.

Woman No.	Independent Variable	Regression Coefficients	t**	P Value	Durbin-Watson d Statistics
No Significant Autocorrelations					
2	constant term	40.94*	70.41	0.0001	1.97
	days	0.56*	5.65	0.0001	
	days^2	-0.02*	-5.72	0.0001	
3	constant term	48.11*	80.32	0.0001	2.08
	days	-0.20*	-2.30	0.0284	
	days^2	0.006*	2.28	0.0302	
11	constant term	47.20*	73.70	0.0001	1.60
	days	-0.08	-0.66	0.5153	
	days^2	0.002	0.55	0.5855	
16	constant term	45.08*	71.33	0.0001	1.53
	days	-0.23*	-2.29	0.0302	
	days^2	0.008*	2.52	0.0179	
17	constant term	43.71*	59.79	0.0001	1.68
	days	0.02	0.18	0.8606	
	days^2	-0.002	-0.57	0.5764	
18	constant term	40.94*	53.04	0.0001	1.30
	days	-0.46	-1.41	0.1925	
	days^2	0.05	1.65	0.1326	
19	constant term	50.39*	98.10	0.0001	1.30
	days	-0.30*	-3.55	0.0015	
	days^2	0.009*	2.98	0.0062	
24	constant term	45.79*	72.60	0.0001	1.82
	days	0.11	1.48	0.1482	
	days^2	-0.002	-1.21	0.2367	
25	constant term	48.55*	79.63	0.0001	1.61
	days	-0.38	-1.86	0.0882	
	days^2	0.02	1.72	0.1104	
27	constant term	50.67*	60.60	0.0001	1.26
	days	-0.03	-0.23	0.8178	
	days^2	0.0005	0.12	0.9061	
28	constant term	44.09*	51.71	0.0001	1.58
	days	0.18	1.17	0.2555	
	days^2	-0.006	-1.11	0.2773	

TABLE G-20. Regressions of Stature^2/Resistance (cm^2/ohm) Versus Days and Days^2 from the Last Menstrual Periods for Each Woman not Taking Oral Contraceptives. (Continued)

Woman No.	Independent Variable	Regression Coefficients	t**	P Value	Durbin-Watson d Statistics
30	constant term	47.99*	67.47	0.0001	1.69
	days	-0.35*	-3.23	0.0032	
	days^2	0.01*	3.14	0.0040	
32	constant term	51.76*	24.94	0.0001	2.18
	days	0.49	0.91	0.3742	
	days^2	-0.04	-1.30	0.2115	
First Order Significant					
33	constant term	30.02*	42.62	0.0001	ρ_3 = -0.52*
	days	0.10	0.96	0.3433	
	days^2	-0.002	-0.66	0.5137	
Second Order Significant					
20	constant term	44.03*	100.08	0.0001	ρ_3 = 0.36*
	days	-0.002	-0.03	0.9760	
	days^2	0.00003	0.02	0.9830	
Third Order Significant					
21	constant term	62.35*	84.40	0.001	ρ_3 = 0.41*
	days	0.26	2.01	1.06	
	days^2	-0.003	-0.58	0.57	
23	constant term	55.53*	72.88	0.0001	ρ_3 = 0.48*
	days	0.20	1.53	0.1404	
	days^2	-0.004	-0.89	0.3816	
31	constant term	38.66*	101.97	0.0001	ρ_3 = 0.40*
	days	-0.14*	-2.49	0.0188	
	days^2	0.005	3.29	0.0027	

* significant at α = 0.05
** statistics for Ho: coefficient = 0

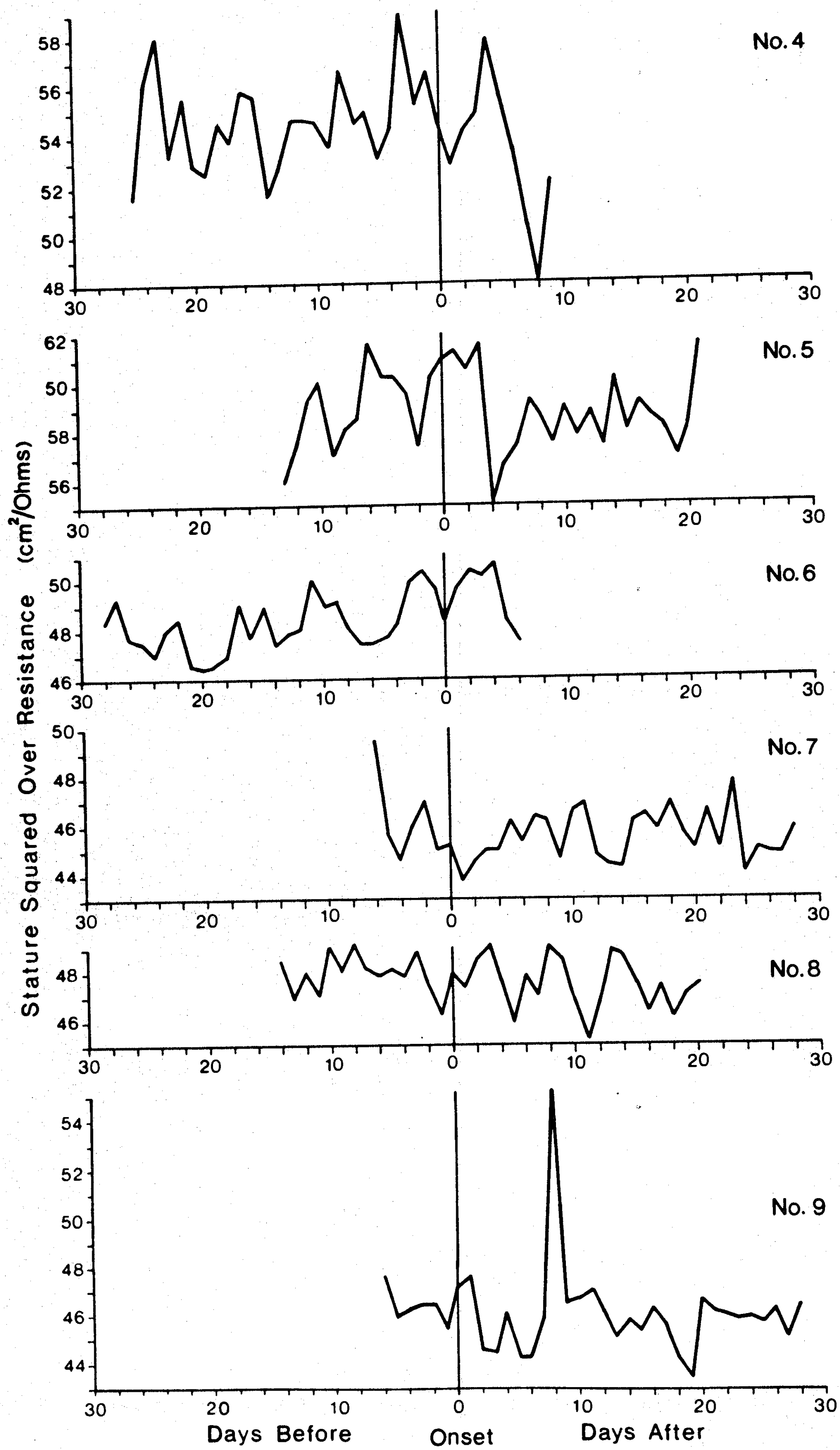

Figure G-1. Daily values of stature^2/resistance during the menstrual cycle in women taking oral contraceptives

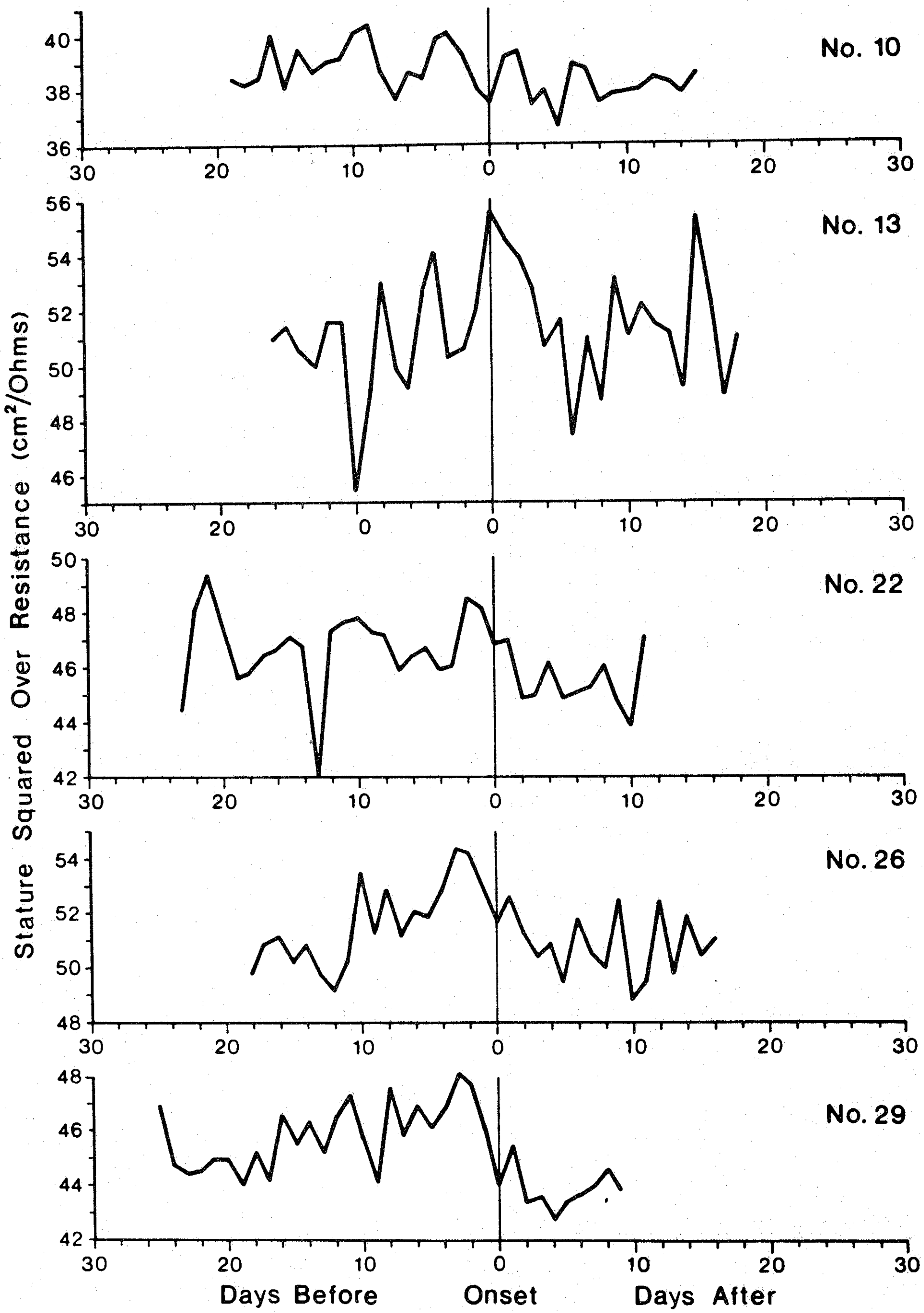

Figure G-1 (Continued). Daily values of stature^2/resistance during the menstrual cycle in women taking oral contraceptives

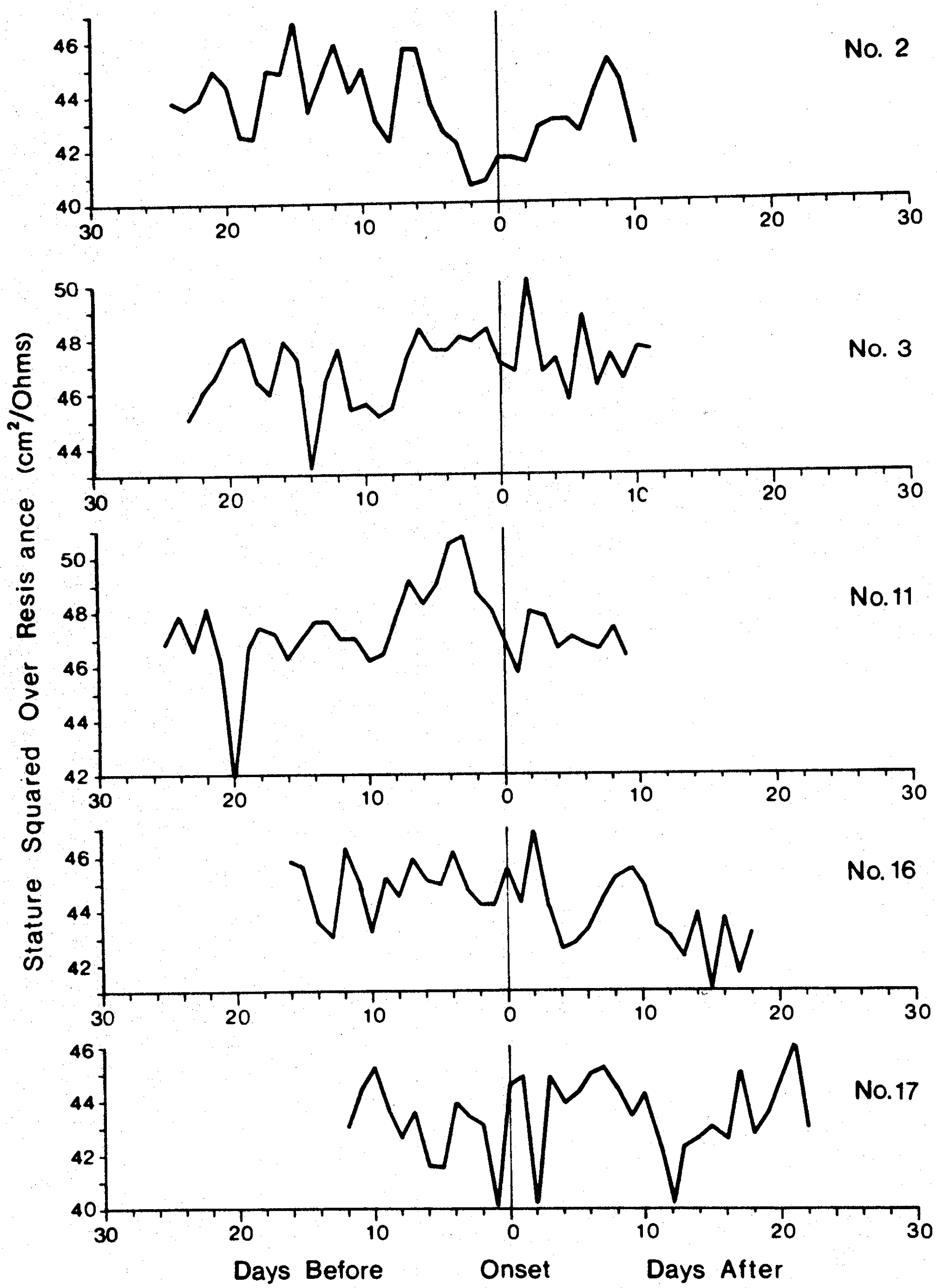

Figure G-2. Daily values of stature^2/resistance during the menstrual cycle in women not taking oral contraceptives

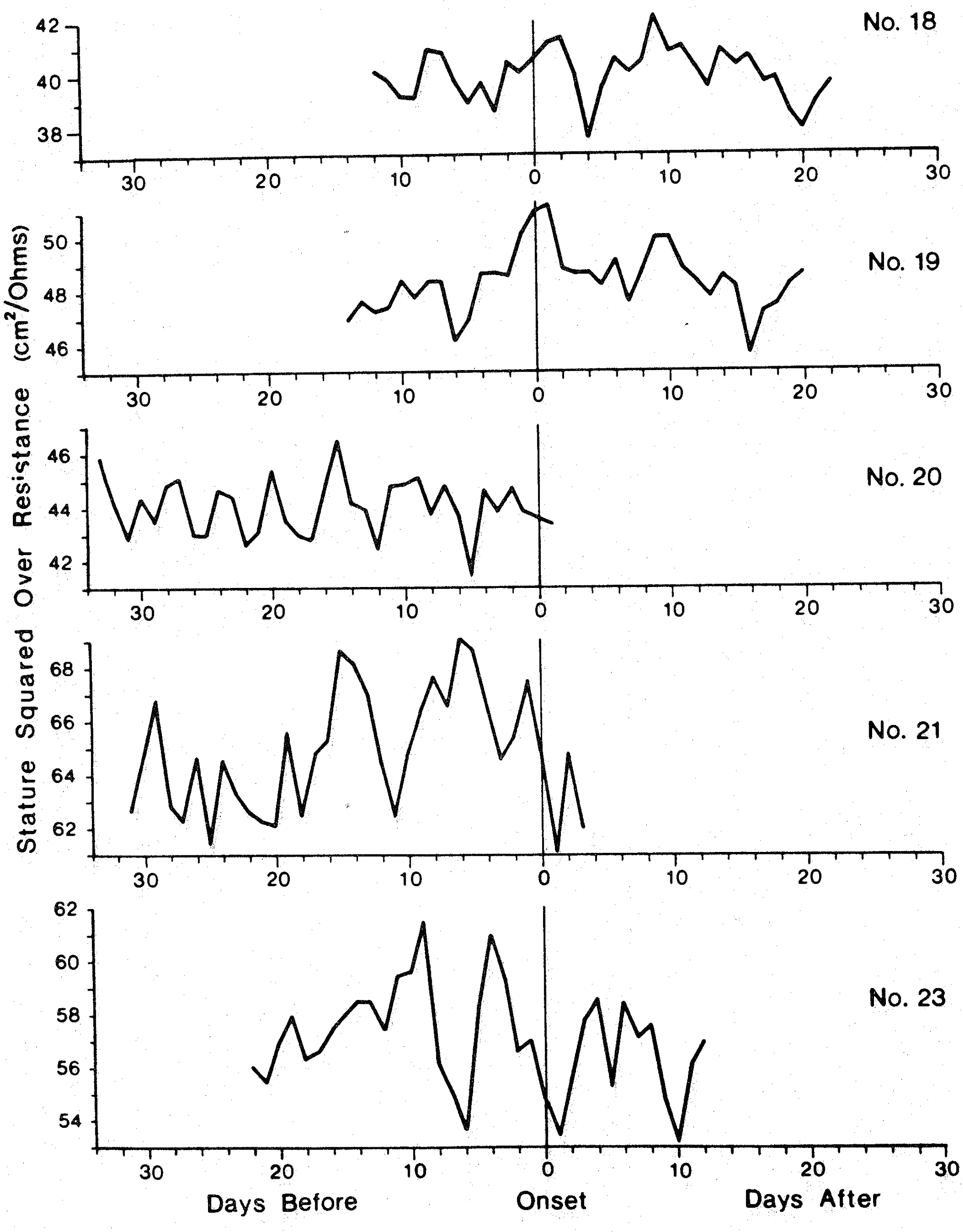

Figure G-2 (Continued). Daily values of stature^2/resistance during the menstrual cycle in women not taking oral contraceptives

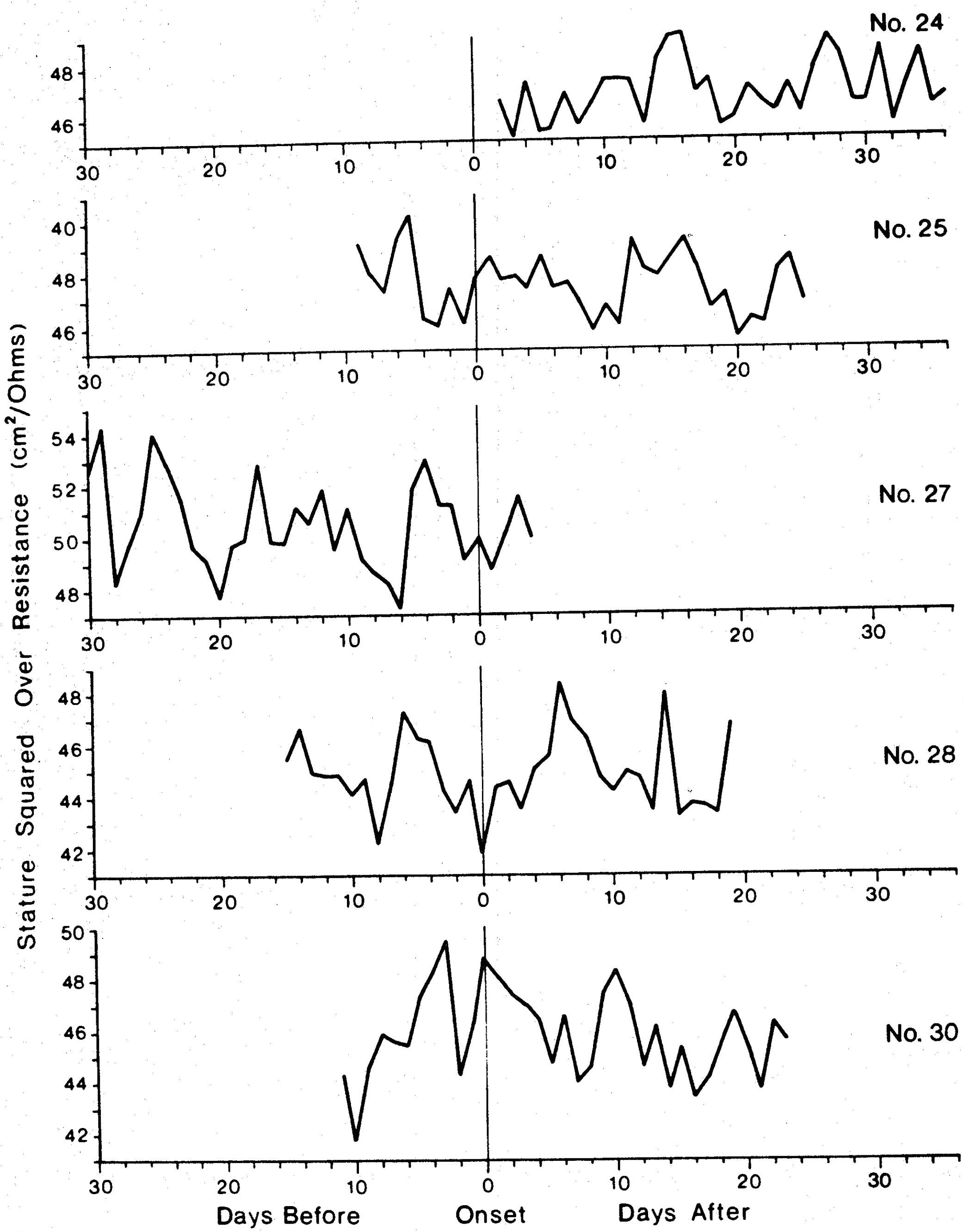

Figure G-2 (Continued). <u>Daily values of stature^2/resistance during the menstrual cycle in women not taking oral contraceptives</u>

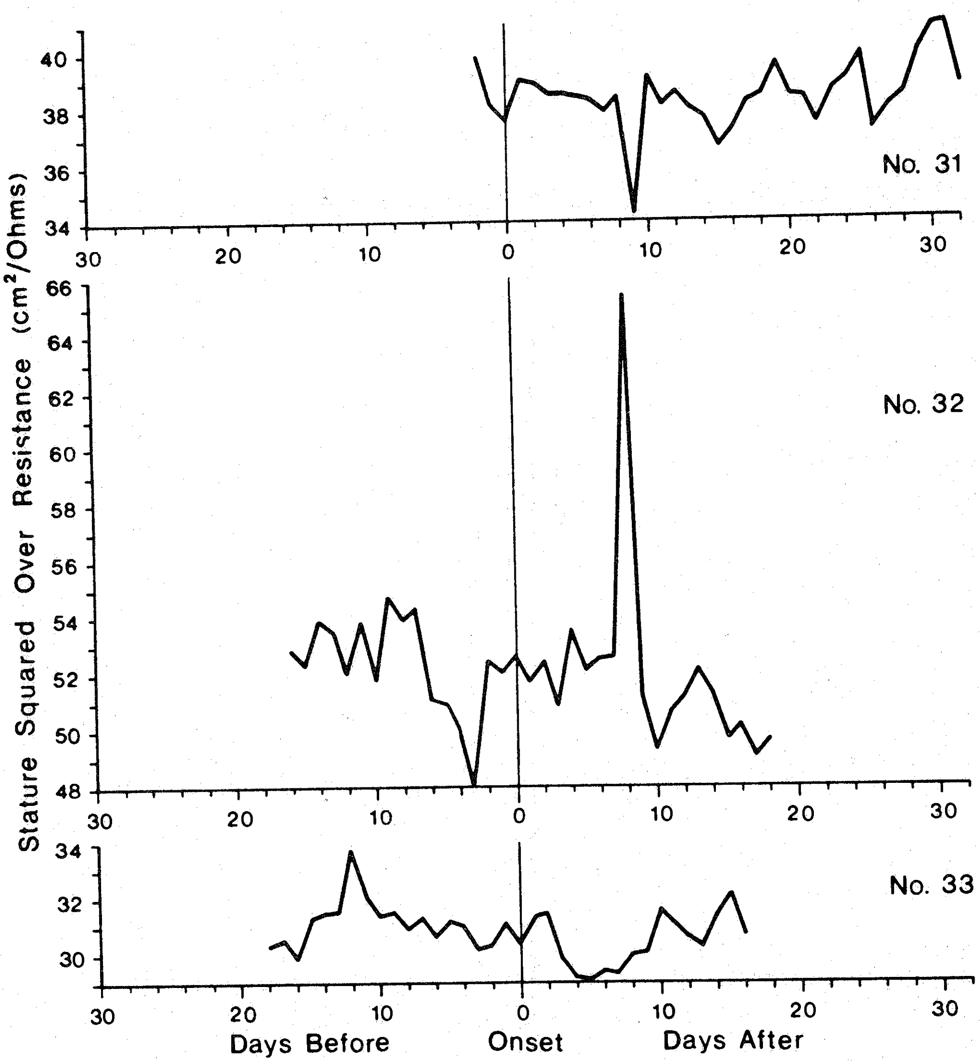

Figure G-2 (Continued). <u>Daily values of stature^2/resistance during the menstrual cycle in women not taking oral contraceptives</u>

APPENDIX H

COMPARISON OF ECHOSCAN 1502 AND LANGE SKINFOLD CALIPER MEASUREMENTS

TABLE H-1. Comparison of EchoScan 1502 Ultrasound and Lange Caliper Measurements in Men.

Variable	DF	Parameter Estimate	Standard Error	t for Ho[b]:	RMSE (mm)
Triceps					
Intercept (mm)	1	-2.62	1.42	-1.85	3.55
Triceps U[a]	1	2.41	0.25	5.62*	
Biceps					
Intercept (mm)	1	0.06	0.47	0.14	1.60
Biceps U[a]	1	1.33	0.13	2.60*	
Subscapular					
Intercept (mm)	1	3.84	1.82	2.12*	4.84
Subscapular U[a]	1	1.47	0.32	1.47	
Midaxillary					
Intercept (mm)	1	-1.32	1.10	-1.21	3.26
Midaxillary U[a]	1	2.07	0.20	5.34*	
Paraumbilical					
Intercept (mm)	1	0.75	2.68	0.28	8.13
Paraumbilical U[a]	1	2.55	0.40	3.86*	
Anterior Thigh					
Intercept (mm)	1	-1.93	1.18	-1.63	3.26
Anterior Thigh U[a]	1	2.42	0.20	7.18*	
Lateral Calf					
Intercept (mm)	1	0.49	0.87	0.56	2.50
Lateral Calf U[a]	1	1.93	0.21	4.48*	

* $0.01 \leq P < 0.05$
** $P < 0.01$

a: Ultrasound
b: t-test for Ho: intercept = 0, and Ho: slope = 1.

TABLE H-2. Comparison of EchoScan 1502 Ultrasound and Lange Skinfold Caliper Measurements in Women.

Variable	DF	Parameter Estimate	Standard Error	t for Ho[b]:	RMSE[c] (mm)
Triceps					
Intercept (mm)	1	5.87	1.88	3.13**	4.74
Triceps U[a]	1	1.73	0.24	3.01*	
Biceps					
Intercept (mm)	1	-0.61	1.08	-0.56	3.27
Biceps U[a]	1	1.89	0.23	3.90*	
Subscapular					
Intercept (mm)	1	0.69	2.33	0.30	6.02
Subscapular U[a]	1	2.03	0.35	2.95*	
Midaxillary					
Intercept (mm)	1	-0.38	1.85	-0.21	4.40
Midaxillary U[a]	1	1.90	0.29	3.04*	
Paraumbilical					
Intercept (mm)	1	10.26	3.22	3.19**	9.13
Paraumbilical U[a]	1	1.72	0.42	1.69*	
Anterior Thigh					
Intercept (mm)	1	4.72	3.11	1.52	5.84
Anterior Thigh U[a]	1	2.23	0.33	3.80*	
Lateral Calf					
Intercept (mm)	1	5.53	1.72	3.21**	3.87
Lateral Calf U[a]	1	1.67	0.29	2.29*	

* $0.01 \leq P < 0.05$
** $P < 0.01$

a: Ultrasound
b: t-test for Ho: intercept = 0, and Ho: slope = 1.
c: RMSE = Root mean square error.

TABLE H-3. Contingency Table Between Skinfold and Ultrasonic Measurements at the Triceps Site in Men.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	11	7	1	0	19
Second	3	9	7	1	20
Third	3	3	10	3	19
Fourth	1	2	2	16	21
Totals	18	21	20	20	79

TABLE H-4. Contingency Table Between Skinfold and Ultrasonic Measurements at the Subscapular Site in Men.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	9	1	8	1	19
Second	4	10	5	1	20
Third	4	6	4	6	20
Fourth	2	3	3	12	20
Totals	19	20	20	20	79

TABLE H-5. Contingency Table Between Skinfold and Ultrasonic Measurements at the Biceps Site in Men.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	8	4	5	2	19
Second	7	8	5	0	20
Third	4	4	7	5	20
Fourth	0	4	3	13	20
Totals	19	20	20	20	79

TABLE H-6. Contingency Table Between Skinfold and Ultrasonic Measurements at the Midaxillary Site in Men.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	7	6	2	0	15
Second	9	7	5	2	23
Third	2	8	8	3	21
Fourth	0	0	5	15	20
Totals	18	21	20	20	79

TABLE H-7. Contingency Table Between Skinfold and Ultrasonic Measurements at the Paraumbilical Site in Men.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	9	5	4	1	19
Second	6	8	4	1	19
Third	2	7	8	4	21
Fourth	2	0	4	14	20
Totals	19	20	20	20	79

TABLE H-8. Contingency Table Between Skinfold and Ultrasonic Measurements at the Anterior Thigh Site in Men.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	10	6	3	0	19
Second	6	10	2	1	19
Third	2	4	9	6	21
Fourth	0	1	6	13	20
Totals	18	21	20	20	79

TABLE H-9. Contingency Table Between Skinfold and Ultrasonic Measurements at the Lateral Calf Site in Men.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	9	4	3	1	17
Second	6	9	6	1	22
Third	4	4	7	5	20
Fourth	0	3	4	13	20
Totals	19	20	20	20	79

TABLE H-10. Contingency Table Between Skinfold and Ultrasonic Measurements at the Triceps Site in Women.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	7	5	3	0	15
Second	5	5	3	3	16
Third	2	4	6	4	16
Fourth	0	3	4	8	15
Totals	14	17	16	15	62

TABLE H-11. Contingency Table Between Skinfold and Ultrasonic Measurements at the Subscapular Site in Women.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	5	5	4	0	14
Second	4	6	2	5	17
Third	4	3	7	2	16
Fourth	2	1	4	8	15
Totals	15	15	17	15	62

TABLE H-12. Contingency Table Between Skinfold and Ultrasonic Measurements at the Biceps Site in Women.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	8	5	0	0	13
Second	5	5	7	1	18
Third	1	4	5	6	16
Fourth	0	2	4	9	15
Totals	14	16	16	16	62

TABLE H-13. Contingency Table Between Skinfold and Ultrasonic Measurements at the Midaxillary Site in Women.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	6	3	3	3	15
Second	6	3	6	1	16
Third	2	6	4	3	15
Fourth	1	3	3	9	16
Totals	15	15	16	16	62

TABLE H-14. Contingency Table Between Skinfold and Ultrasonic Measurements at the Paraumbilical Site in Women.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	5	5	4	1	15
Second	5	4	2	4	15
Third	3	2	6	6	17
Fourth	2	5	4	4	15
Totals	15	16	16	15	62

TABLE H-15. Contingency Table Between Skinfold and Ultrasonic Measurements at the Anterior Thigh Site in Women.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	7	8	0	0	15
Second	2	5	8	1	16
Third	5	1	5	5	16
Fourth	0	3	3	9	15
Totals	14	17	16	15	62

TABLE H-16. Contingency Table Between Skinfold and Ultrasonic Measurements at the Lateral Calf Site in Women.

	Ultrasonic Quartiles				
	First	Second	Third	Fourth	Total
Caliper Quartiles					
First	6	5	4	0	15
Second	3	4	4	5	16
Third	6	3	4	3	16
Fourth	0	3	5	7	15
Totals	15	15	17	15	62